2015 July 1st–5th
Aalborg, Denmark

MEMRO

7th International Symposium
on Middle Ear Mechanics in Research and Otology

Conference program and abstracts

AALBORG UNIVERSITY
DENMARK

AALBORG UNIVERSITY HOSPITAL

POSTER AWARDS

A poster prize of 500 € will be awarded for the best poster in both basic and clinical sciences.

We kindly ask all participants to take part in this by placing their sticker marks on their own personal choice for the best poster in the two groups. At the end of the meeting the total votes will determine the awards, and it will be announced at the closing session.

Sponsors

The MEMRO2015 has been supported by

- Aalborg University Hospital
- The Obel Family Foundation
- Aalborg University

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Contents

ME = Middle Ear

2015 July 1st–5th Aalborg, Denmark MEMRO

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- Joris JJ Dirckx, Antwerp, Belgium
- Magnus von Unge, Oslo, Norway

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- K-B Hüttenbrink, Cologne, Germany
- Michael McKenna, Boston, USA
- Sunil Puria, Stanford, USA
- John Rosowski, Boston, USA
- Thomas Zahnert, Dresden, Ger-many

International Guest Faculty

- Bernard Ars, Bruxelles, Belgium
- Dirk Beutner, Cologne, Germany
- Mathias Bornitz, Dresden, Germany
- W Robert J Funnell, Montreal, Canada
- Evert Hamans, Antwerp, Belgium
- Hannes Maier, Hannover, Germany
- Marcus Neudert, Dresden, Germany
- Stefan K. Plontke, Halle, Germany
- Juha Silvola, Oslo, Norway
- Mads S Sørensen, Copenhagen, Denmark
- Haruo Takahashi, Nagasaki, Japan
- Abigail Tucker, London, Great Britain

Venue Area

Utzon Center
Utzon Parken
Musikkens Plads
Bikuben Kollegiet
Bikuben Kollegiet
Bikuben Kollegiet
Create Building
Aalborghus
CabInn
First Hotel Aalborg
Nyhavnsgade
Nyhavnsgade
Gammel Havn
Rendsburggade
Slotsgade
Fjordgade
Gabels Torv
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Kaffé Fair
Aalborg HOBBY Service
Socialistemes Hus
Rendsburggade
Fjordgade
Waterfront
Auditorium
Canteen
Toilets
Wardrobe
Hall
Courtyard

Welcome to MEMRO 2015

7th International Symposium
on Middle Ear Mechanics in Research and Otology

In a few weeks three years has already passed since the last prominent MEMRO2012 meeting in Daegu, South Korea, and it is time for the current MEMRO2015 meeting. In order to bring our objective and work on hearing improvements forward, the successful interdisciplinary approach of the MEMRO society is even more required due to the progress in technology. The MEMRO enables the intensive dialog between basic researchers and clinical otosurgeons, where the latest improvements in prostheses, active implants and other technologies will be discussed along with the clinical problems and surgical reconstructions related to hearing deficits. These aspects are all closely related to the basic understanding of the middle ear physiology and pressure regulation.

The venue of the MEMRO2015 in Aalborg, Denmark, was selected at the last meeting in 2012, and we have been through an intensive planning in order to organize both the facilities and the program for another successful meeting. The new City Campus of the "Create Building" of Aalborg University was inaugurated only last summer, and it will provide us with all facilities needed for such a meeting, where an auditorium is available together with ample space for poster and sponsor exhibitions. This City Campus is situated right at the new harbor front with the auditorium overlooking the water, and the hotels as well the reception site of the Utzon Center are all within comfortable walking distance. Similarly, the city center of Aalborg is right behind the harbor front for your pleasure.

The program has been brought together with a number of key note sessions together with 114 individual abstracts representing the most recent research in our field from all over the world. The content of the program is almost in tradition with previous meetings quite dense, and we are all in for long days and late hours. However, the MEMRO is also renowned for its relaxed and dedicated atmosphere with friendships across the world; the current registration counts more than 170 participants.

Thus, we should have all the prerequisites at hand for an intimate and successful venue and we hope you will enjoy another great MEMRO meeting.

Welcome to MEMRO2015 in Aalborg – Denmark!

Magnus von Unge, Oslo – Norway
Joris Dirckx, Antwerp – Belgium
Michael Gaihede, Aalborg – Denmark

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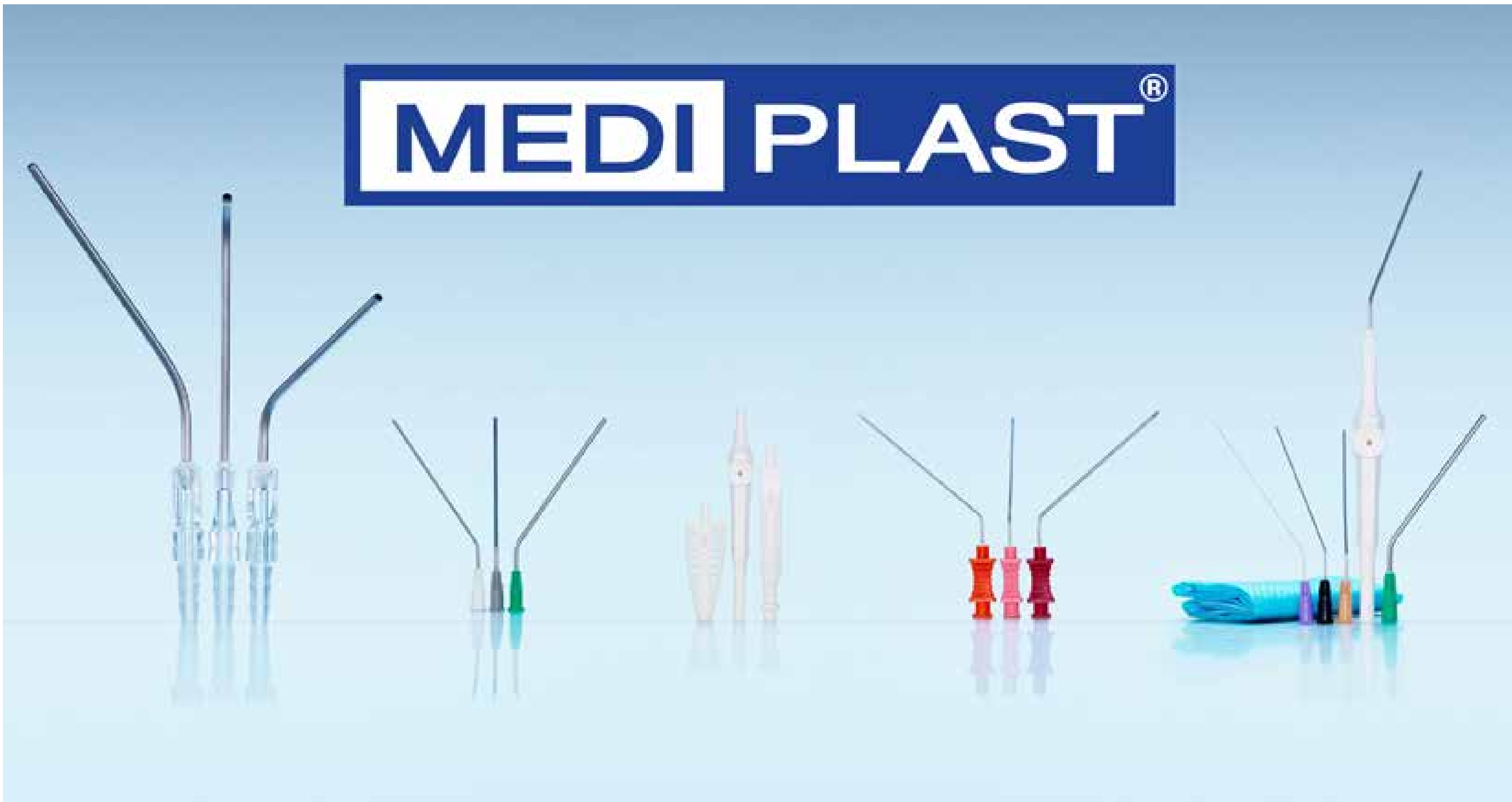

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Program at a glance

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17.30-18.00 Regis-tration at the Utzon Center

(The desk will also be open on Thurs-day morning from 07.30 at the Create Build.)

18.00-21.00 Official opening of the MEMRO and Reception at the Utzon Center</td><td>08.00-08.15</td><td>Opening remarks</td><td rowspan="2">08.00-08.45</td><td rowspan="2">Keynote 3 (45 min)

Prof. Evert Hamans</td></tr>
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W Robert J Funnell</td><td>13.45-14.30</td><td>Keynote 4 (45 min)
Prof. Bernard Ars</td></tr>
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ME Biomechanics (II)</td><td>15.45-17.15</td><td>Session B4
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Saturday, 4th July		Sunday, 5th
08.00-08.45	*Keynote 5* (45 min) Abigail Tucker	**All day excursion to Skagen.** **Departure from First Hotel at 09.00 hours.**
08.45-09.45	**Session C1** Evolution, Development and Imaging	
09.45-10.00	Conference Photo	
10.00-10.30	Coffee break – Poster	
10.30-11.30	*Keynote 6* Prof Haruo Takahashi	
11.30-12.30	**Session C2** ME Physiology and pressure regulation	
12.30-13.30	Lunch break – Poster	
13.30-15.15	**Session C3** Surgical techniques and Reconstruction	
15.15-16.00	Closing session • MEMRO2018 Presentations • Poster Awards	
18.00	Bus for Conference Dinner	**17.15 Airport drop off**

Detailed program

THURSDAY – July, 2nd	
08.00-08.15	**Opening remarks**
08.15-08.35	**Memorial lecture – John Rosowski on Saumil Merchant**
08.45-09.30	**Keynote 1. Dorte Hammershøi, Aalborg, Denmark** (45 min). Sound transmission to and within the human ear canal and its significance for localization. **Moderator: Michael Gaihede**
09.30-10.15	**Coffee break – Poster**
10.15-12.15	**Session A1 (8) – ME Active Implants (I)** **Moderator: Hannes Maier & Stefan Plontke** **10.15.** Development of 3-Coil Bellows Type Middle Ear Transducer for Round Window Stimulation. **Dong Ho Shin, Daegu, Korea**. **10.30.** Can stapes velocity be used to estimate the efficacy of mechanical stimulation of the round window of the cochlea with an active middle ear prosthesis? **Daniel J Tollin, Aurora, Co, USA**. **10.45.** A method to characterize the output of active middle ear implants in temporal bone experiments using a commercial pressure sensor. **Martin Grossöhmichen, Hannover, Germany**. **11.00.** A novel air-filled middle-ear implant for non-aerated ears: Progress report. **Michael E. Ravicz, Boston, Ma, USA**. **11.15.** A preliminary study of acoustic stimulation at the lateral canal. **Nicolas Verhaert, Leuven, Belgium**. **11.30.** Active middle-ear implant fixation in incus vibroplasty. **Sebastian Schraven, Würzburg, Germany**. **11.45.** Comparison of alternative coupling methods of the Vibrant Soundbridge FMT. **Susan Busch, Hannover, Germany**. **12.00.** Effects of loads and coupling techniques on the efficiency of the backward stimulation of the cochlea with the floating mass transducer. **Antoniu Gostian, Cologne, Germany**.
12.15-13.15	**Lunch break – Poster**
13.15-14.00	**Keynote 2. W Robert J Funnell, Montreal, Canada** (45 min). Finite-element modelling of the middle ear. **Moderator: Joris Dirckx**

14.00-15.00	**Session A2 – ME Biomechanics (4)** **<u>Moderator: Kiyofumi Gyo and John Rosowski</u>** **<u>14.00.</u>** Experimental investigation of the spatial motion of malleus and incus for sound induced vibrations. **Albrecht Eiber, Stuttgart, Germany**. **<u>14.15.</u>** Measurement of elastic properties of the stapes annular ligament using AFM technique. **Marcin Michalowski, Warsaw, Poland**. **<u>14.30.</u>** Biomechanics of the Incudo-Malleolar Joint – Numerical and Experimental Investigations for Quasi-Static Loads. **Sebastian Ihrle, Stuttgart, Germany**. **<u>14.45.</u>** A single-ossicle ear: acoustic response and mechanical properties measured in duck. **Pieter GG Muyshondt, Antwerp, Belgium**.
15.00-15.30	**Coffee break – Poster**
15.30-17.30	**Session A3 – ME Biomechanics (continued) (8)** **<u>Moderator: Hideko Heidi Nakajima and Marcus Neudert</u>** **<u>15.30.</u>** Superior Semicircular Canal Dehiscence (SSCD): temporal bone experiments and clinical symptoms. **Karl-Bernd Hüttenbrink, K**öln, Germany**.** **<u>15.45.</u>** Motion of Tympanic Membrane in Guinea Pig Otitis Media Model Investigated by Scanning Laser Vibrometry and Finite Element Modeling. **Xuelin Wang, Norman, OK, USA**. **<u>16.00.</u>** Mechanical Damage of Tympanic Membrane in Relation to Impulse Pressure Waveform – A Study in Chinchillas. **Rong Z Gan, Norman, OK, USA**. **<u>16.15.</u>** Motion of Tympanic Membrane Surface Produced by Reverse Mechanical Stimulation. **Jeffrey Tao Cheng, Boston, MA, USA**. **<u>16.30.</u>** On the connection between the eardrum and the malleus: a detailed study through micro-CT and histology. **Daniel De Greef, Antwerp, Belgium**. **<u>16.45.</u>** Response of the human tympanic membrane to transient acoustic and mechanical stimuli. **Michael Ravicz, Boston, MA, USA**. **<u>17.00.</u>** Sound transmission via the malleus-incus complex. **Ivo Dobrev, Zürich, Switzerland**. **<u>17.15.</u>** The impact of a cochlear implant electrode array on middle ear transfer function. **Dirk Beutner, Cologne, Germany**.
17.30	Adjourn

FRIDAY – July, 3rd	
08.00-08.45	**Keynote 3. Prof. Evert Hamans, Antwerp, Belgium** (45 min). The clinical consequences of interaural attenuation. **Moderator: Joris Dirckx**
08.45-10.15	**Session B1 – Computational Models (6)** **<u>Moderator: Michael McKenna and Thomas Zahnert</u>** <u>**08.45.**</u> Testing the effects of variations in human tympano-ossicular chain geometry and material properties on middle-ear sound transmission using 3D finite-element models. **Charles Steele, Stanford, CA, USA**. <u>**09.00.**</u> Modelling of cochlear hydrodynamics before and after stapedotomy using new FSI model. **Konrad Kamieniecki, Warsaw, Poland**. <u>**09.15.**</u> On the influence of anatomical variations on METF - theoretical investigations using a finite element model. **Steffen Oßmann, Dresden, Germany**. <u>**09.30.**</u> Precision of ossicular motion reconstructed from 1D and 3D-LDV measurements. **Pascal Ziegler, Stuttgart, Germany**. <u>**09.45.**</u> Statistical shape modeling of the incudomalleolar complex using micro-CT and clinical cone-beam CT. **Joris AM Soons, Antwerp, Germany**. <u>**10.00.**</u> Virtual reality in ear surgery 2015 and beyond. **Mads Sølvsten Sørensen, Copenhagen, Denmark**.
10.15-10.45	**Coffee break – Poster**
10.45-12.45	**Session B2 – ME Active Implants (II) (8)** **<u>Moderator: Michael E Ravicz and Dirk Beutner</u>** <u>**10.45.**</u> Efficiency of the Codacs™ Actuator in Alternative Stimulation Applications of the Stapes. **Hannes Maier, Hannover, Germany**. <u>**11.00.**</u> Electroacoustical model of floating-mass transducer stimulation of the middle ear. **Ernst Dalhoff, Tübingen, Germany**. <u>**11.15.**</u> Evaluation of coupling conditions of an active middle ear implant (Vibrant Soundbridge) using Laser-Doppler Vibrometry in vivo. **Frank Böhnke, Munich, Germany**. <u>**11.30.**</u> Fully implantable hearing aid in the incudostapedial joint gap. **Martin Koch, Dresden, Germany**. <u>**11.45.**</u> Importance of Controlled Static Contact Force in Mechanical Round Window Stimulation. **Rolf Salcher, Hannover, Germany**. <u>**12.00.**</u> Mechanical stimulation of the umbo using a light-activated contact hearing device: Maximum equivalent pressure output and maximum stable gain measurements in temporal bones and model calculations. **Sunil Puria, Stanford, CA, USA**.

	12.15. Stapes velocities and intracochlear pressures for two modes of direct mechanical stimulation. **James R Easter, Boulder, CO, USA**. **12.30.** Comparison of Audiological Results of the Bonebridge to a Percutaneous Device. **Thomas Giere, Hannover, Germany**.
12.45-13.45	**Lunch break – Poster**
	Meeting of the Scientific Committee *(room will be announced)*
13.45-14.30	**Keynote 4. Prof. Bernard Ars, Bruxelles, Belgium** (45 min) Middle Ear Cleft Pressure Regulation. Morphological and Physiological Aspects. **Moderator: Michael Gaihede**
14.30-15.15	**Session B3 – Diagnostics (3)** **Moderator: Rong Z Gan and Dan D Hougaard** **14.30.** Aural acoustic wideband measurements in infants of ambient and tympanometric reflectance and equivalent admittance. **Douglas H. Keefe, Omaha, NE, USA**. **14.45.** Creating borderline situations in middle ear surgery: is there a value of virtual tympanotomy? **Christian Offergeld, Freiburg, Germany**. **15.00.** Effects of static negative middle ear pressure on wideband acoustic immittance. **Jont Allen, Urbana, IL, USA**.
15.15-15.45	**Coffee break – Poster**
15.45-17.15	**Session B4 – Bone Conduction (6)** **Moderator: Alex Huber and Hanif Ladak** **15.45.** Model predictions of bone conduction hearing in the human. **Stefan Stenfelt, Linköping, Sweeden.** **16.00.** Bone conduction: what contributes to Carhart's notch? **Hideko Heidi Nakajima, Boston, MA, USA.** **16.15.** Bonebridge® implant in adults and children: computer assisted 3D planning and audiological outcome. **Stefan Plontke, Halle, Germany.** **16.30.** BAHA Attract – first Nordic results on a new transcutaneous bone conduction hearing solution. **Dan D Hougaard, Aalborg, Denmark.** **16.45.** Application of bone conduction implants Med-El Bonebridge in adult patients with congenital or acquired hearing loss – first experience. **Maciej Mrowka, Warsaw, Poland.** **17.00.** Intracranial sound pressure during BC stimulation. **Christof Röösli, Zürich, Switzerland.**

17.15-18.30	**Workshop – The ME transfer function – Refreshments incorporated** **Moderator: Matthias Bornitz and Hiroshi Wada**
18.30	Adjourn – Guided City Walk (optional – preregistration needed)

SATURDAY – July, 4th	
08.00-08.45	**Keynote 5. Abigail Tucker, London, Great Britain** (45 min) A developmental biology approach to understanding the middle ear. Moderator: Michael Gaihede
08.45-09.45	**Session C1 – Evolution, Development, and Imaging (4)** **Moderator: Anthony Gummer and Mads S Sørensen** **08.45.** Changes in dynamic characteristics of the external ear canal wall during the first 3 months of life. **Michio Murakoshi, Kagoshima, Japan**. **09.00.** Evolution of modern human middle ear ossicles – Evidence from extant and extinct species. **Alexander Stoessel, Leipzig, Germany**. **09.15.** Signaling of different Wnt pathway members accompany the developmental processes of middle ear formation. **Ulrike J. Sienknecht, Oldenburg, Germany**. **09.30.** High frequency ultrasound and optical coherence tomography: New technologies for non-invasive high resolution middle ear imaging and vibrometry. **Thomas Landry, Nova Scotia, Canada**.
09.45-10.00	**Conference Photo – Staircase in the hall area**
10.00-10.30	**Coffee break – Poster**
10.30-11.30	**Keynote 6. Prof. Haruo Takahashi, Nagasaki, Japan** (60 min) Middle ear pathophysiology and management viewed from pressure-regulation function. Moderator: Michael Gaihede
11.30-12.30	**Session C2 – ME Physiology and Pressure Regulation (4)** **Moderator: Christian Offergeld and Jont Allen** **11.30.** Ossicular chain motion during low frequency and high intensity sound stimulation. **Nathaniel T Greene, Aurora, CO, USA**. **11.45.** Congestion of mastoid mucosa and influence on middle ear pressure. **Pernille VF Jensen, Aalborg, Denmark**. **12.00.** Tympanic membrane pressure buffering in the quasi-static pressure regime. **Wasil HM Salih, Khartoum, Sudan**. **12.15.** Determination of the mastoid surface area and volume based on micro-CT-scanning of human temporal bones. Geometrical parameters dependence on scanning resolutions. **Olivier Cros, Aalborg, Denmark**.
12.30-13.30	**Lunch break – Poster**

13.30-15.15	**Session C3 – Surgical Techniques and Reconstruction (8)** **<u>Moderator: Sunil Puria and Christof Röösli</u>** **<u>13.30.</u>** Intraoperative Online Monitoring of Ossiculoplasty using LDV – first clinical measurements. **Thomas Zahnert, Dresden, Germany.** **<u>13.45.</u>** Intra-operative assessment of ossicular fixation. **John Peacock, Antwerp, Belgium.** **<u>14.00.</u>** A new flexible TORP with silicone coated ball joint and its properties. **Thomas Stoppe, Dresden, Germany**. **<u>14.15.</u>** Round window vibration induced by new chamber stapes prosthesis: preliminary results of experimental investigation. **Magdalena Solyga, Warsaw, Poland**. **<u>14.30.</u>** Influence of Prosthesis' Length on Middle Ear Transfer Function. **Marcus Neudert, Dresden, Germany**. **<u>14.45.</u>** Titanium PORP's and TORP's versus autologous ossicles. Clinical results in 337 tympanoplasties. **Ayhan Al Kole, Aalborg, Denmark**. **<u>15.00.</u>** Theoretical and Practical Considerations of 3-Dimensionally Printed Biomimetic Tympanic Membrane Grafts: Preliminary Design, Manufacture, and Acoustic Testing. **Aaron Remenschneider, Boston, MA, USA**.
15.15-16.30	**Closing session** **<u>Moderator K-B Hüttenbrink and Michael Gaihede</u>** **15.15.** MEMRO 2018 – presentations and voting **15.45.** Poster Awards **16.00.** Closing remarks
18.00	Bus for Conference Dinner from First Hotel

Workshop on ME transfer function

- measurement techniques and measurement databases

Friday, July, 3rd, 17.15-18.30

BACKGROUND

In 2007 the research group from Boston published on a standardized procedure to evaluate implantable hearing aids (Rosowski, 2007 and ASTM_F2504_05). They also provided collected data of middle ear transfer functions (METF). These data had been published by different labs over the last 3 decades and was obtained with different measurement techniques. Many research groups use these data collection as reference data for METF. This emphasizes the need for a common database for reference data.

However, up to now we have these mean data only and sometimes a few individual METF, always presented in diagrams only. The data is also often presented in different scales and units. All this additionally complicates valid comparison of the data and its further usage. Due to a lack of sufficient supporting data it is sometimes not clear whether different data really exactly represent the same physical quantities. Moreover, the phase data of METF and of individual METF are constantly missing. Furthermore, as temporal bone specimens are rare and valuable all published measurement data should be provided in a structure and extent that allows optimal further usage within the research community (e.g. as reference data or for model validation).

AIM

The round table discussion should provide valuable comprehensive information on METF measurement and technique for all dealing (or just starting) with experimental middle ear research. The information will support labs in the setup of measurements and will help to avoid mistakes and thus to save specimen. The audience in general will benefit from information on how to interpret and judge published measurement data.
The session aims to start a process to define common standards in middle ear measurements, to provide reference data via data exchange and a measurement database and to support further usage of published measurement data.

WORKSHOP OUTLINE

- Introduction of the planned measurement database (structure and content of the measurement data and supporting information that should be provided)
- Overview of current data, showing the current range of METF (all labs that are interested in sharing their data should provide some METF in a standardized format anonymously beforehand)
- Short statements (around 5 min.) on special topics concerning measurement techniques, e.g.:
    - factors that influence measurement data like position of the reference microphone, position of measurement point, angle, etc.
    - correct phase measurement, calibration and equalization
    - different kinds of METF, single point vs. volume displacement vs. inner ear pressure vs. round window sound radiation
- Short discussion on the planned structure and content of the planned measurement database (just questions of common interest, also for non-experimenters. There will be time aside the lectures for in depth)

ORGANIZERS AND PARTICIPANTS

Current participants: Matthias Bornitz, Marcus Neudert (Dresden), Dirk Beutner, David Pazen (Cologne), Alex Huber (Zurich), Albrecht Eiber (Stuttgart), Thomas Landry (Halifax), W Robert J Funnell (Montreal).

Social program

RECEPTION AT THE UTZON CENTER ON WEDNESDAY, JULY, 1ST AT 18.00-21.00
(Registration needed; included in the registration fee)

This art and architecture exhibition center has been constructed by Jørn Utzon and his sons. Jørn Utzon was raised in Aalborg and he is world renowned for the Opera House in Sidney. This building is more modest, but houses exhibition facilities including an auditorium and atrium, which will host our reception.

17.30 The registration desk is open at the Utzon Center

18.00 Official opening of the MEMRO 2015 at the auditorium
- The Organizing Committee's welcome
- The Mayors welcome
- "Be greeted in the halls of Freja" which is an entertaining review of the Viking age in Scandinavia and Europe by Jesper Lynge, who is the manager of the Lindholm Høje Museum. This museum is one of the largest Viking burial grounds from around 1000 AC in Northern Europe. Jesper Lynge is devoted to the history of the Vikings and cooking during this period.

19.00 Reception with drinks and light dinner

GUIDED CITY WALK ON FRIDAY, JULY, 3RD AT 18.00-19.30
(Registration needed)

This guided tour will take you along the recently renovated harbor front, the Music House, Nordkraft, as well as the older picturesque 17th Century houses of the inner city.

CONFERENCE DINNER – ROBBERS' BANQUET ON SATURDAY, JULY, 4TH AT 18.00-23.00
(registration needed; included in the registration fee)

The conference dinner will be held in one of the larger forests in Denmark, Rold Forest, where a convenient Robbers' Camp will host us with entertainment and dinner – since this is an outdoor activity, please bring robust foot wear and an extra sweater. The camp is shielded with roofing in the tree tops to keep us dry in case of an occational shower.
The Scandinavian midsummer has an enchanting atmosphere with long hours of light in the evenings, and the setting beneath the beeches with camp fire will make it a memorable evening

EXCURSION TO SKAGEN ON SUNDAY, JULY, 5TH AT 09.00-17.30
(Registration needed)

Skagen is one of the most popular holiday regions in Scandinavia due to its nature of wide open areas of dunes and beaches as well as the picturesque village and fishing harbor, which during summer time is crowded with yachts. On the way to Skagen we will visit Råbjerg Mile, which is a colossal dune on its constant long journey across land from west to east coast. In Skagen we will see the Skagen Museum with paintings from the Golden Age in Scandinavian art at the end of the 19th Century, and we will settle for lunch at the harbor in Pakhuset – an old fish store house. In the afternoon we will go to Grenen, which is the top of the continent, where the Skagerak and Kattegat meet; the last part of this trip will be in a tractor driven wagon to overcome the heavy sand of the beach.

On the way back to Aalborg, we will make a stop at the airport at 17.15 for those, who have flights out of Aalborg in the evening.

Oral presentations

Session A1

Topic: ME Active Implants (I)

A1-1) Development of 3-coil bellows type middle ear transducer for round window stimulation

Dong Ho Shin, Graduate School of Electronics Engineering, Kyungpook National University, Daegu, Korea;
Ki Woong Seong, Department of Biomedical Engineering, Kyungpook National University Hospital Daegu, Korea; Sunil Puria, Departments of Mechanical Engineering and Otolaryngology–HNS,Stanford University, USA; Jin-Ho Cho, School of Electronics Engineering, College of IT Engineering, Kyungpook National University, Daegu, Korea;
Graduate School of Electronics Engineering, Kyungpook National University, Daegu, Korea

Round window (RW) driving type implantable middle ear hearing aids using a floating mass transducer (FMT) have been attracting attention as a FMT is easy to implant in a RW niche. Yet according to some studies, the RW driving method using a FMT has a notably low vibration gain in a low frequency region. A FMT consists of two parts: the magnet and the cylindrical case, and the ideal frequency characteristics occur when these two parts have the same mass. However, the loading effect of the FMT increases with an increase in the degree of contact between the tissue and the outer case. Thus, since the induced reaction force of the outer case due to the magnet vibration is low at a low frequency, the gain attenuation is more significant at a low frequency than at a high frequency. Accordingly, this study proposes a new 3-coil bellows-type transducer (TCBT), which is similar in size to a FMT, for use with a RW implant. The structure of the TCBT differs from that of a FMT in 2 ways; first, the cylindrical case of the TCBT is fixed to the RW niche, so it does not vibrate. Second, the internal end of a tiny bellows membrane is connected to a vibrating 3-pole magnet located inside 3 coils, while the open rim of the bellows is attached to the end of the cylindrical case covering the 3 coils. Therefore, the only vibrating element is the bellows membrane, which directly drives the RW membrane. Experimental results show that the proposed transducer has excellent frequency characteristics in the audible frequency region. Therefore, it is expected that the proposed bellows transducer can be used for RW driving-type implantable middle ear hearing aids.

A1-2) Can stapes velocity be used to estimate the efficacy of mechanical stimulation of the round window of the cochlea with an active middle ear prosthesis?

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Background: Mechanical stimulation of the round window (RW) membrane with active middle ear prostheses (AMEPs) has shown benefits in patients with mixed hearing loss. Standards based on measurements of stapes velocities (SV) exist to objectively assess AMEP performance in human cadaver specimens when coupled to the ossicular chain. Here, SV is a reasonable measure of cochlear input via the AMEP because the system is driven in the forward direction. These standards may not be applicable, however, when the AMEP stimulates the cochlea through the RW. During RW stimulation, SVs are expected to be more complex due to driving the cochlea in the reverse direction and the potential effects of cochlear “third windows”.
Methods: Here we tested this hypothesis by measuring the cochlear microphonics (CM) and SV in nine ears in five chinchillas in response to both acoustic (forward direction) and RW stimulation with an AMEP (reverse direction). For each stimulus frequency, CM amplitude and SV was measured as a function of intensity (dB SPL or dB mV). For the same CM amplitude output we assumed that the same vibrational input to the cochlea was present regardless of the route of stimulation. Here, equivalent vibrational input to the cochlea was determined by equating the acoustic and AMEI-generated CM amplitudes.

Results: The measured SV for equivalent CM amplitudes from the two types of input were not significantly different for low and medium frequencies (0.25-4 kHz); however, SV for AMEI-RW drive were significantly lower than for equivalent acoustic stimuli for higher frequencies (4-14 kHz). The results demonstrate that measured SVs when stimulating the RW underestimate the actual mechanical input to the cochlea by ~20 dB for frequencies above 4 kHz.
Conclusions: The possible influences of cochlear third windows are discussed as well as alternative methods to assess AMEP performance when driving the RW.

A1-3) A method to characterize the output of active middle ear implants in temporal bone experiments using a commercial pressure sensor

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Introduction: Differential sound pressure between scala vestibuli (SV) and scala tympani (ST) is known to correlate with cochlear excitation (Dancer and Franke, 1980). Measurement of this pressure difference is therefore a potential method to characterize the output of active middle ear implants or acoustic implants in temporal bone (TB) experiments. Intracochlear pressure measurements have been published before (e.g. Olson, 1998), using a custom-made pressure sensor. However, in order to make this method accessible to a wider community, the feasibility of intracochlear pressure measurements with a commercially available pressure sensor was tested in this study.
Methods: Experiments were performed in cadaveric human TBs compliant to the modified acceptance criteria of ASTM F2504-05 (Rosowski et al., 2007). Sound was applied to the tympanic membrane (TM) between 0.1 and 10 kHz (sequence of sine wave signals, resolution of ~ 3/octave). Simultaneously pressures in SV (PSV) and ST (PST) were measured with two commercially available fiber-optic pressure sensors (Samba Preclin 420 LP). Sound pressure level at the TM was recorded with a probe microphone, vibration response at the stapes footplate (SFP) was measured with a laser Doppler Velocimeter (LDV, Polytec).
Results: Between 0.1 and 8 kHz sound pressures in SV and ST were measurable with signal-to-noise ratio (SNR) > 12 dB. Pressure differences (P_SV – P_ST) normalized to outer ear canal sound pressure level and to SFP velocity were comparable to results from experiments with a custom-made pressure sensor reported by Nakajima et al. (2009), Pisano et al. (2012) and Stieger et al. (2013).
Conclusion: Differential sound pressure between SV and ST can be determined with the commercially available pressure sensor Samba Preclin 420 LP with sufficient SNR and sensitivity.
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A1-4) A novel air-filled middle-ear implant for non-aerated ears: Progress report

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Introduction: Middle-ear effusion is a common cause of conductive hearing loss of up to 40–60 dB. Middle-ear (ME) fluid inhibits motion of the tympanic membrane (TM) in response to sound. Small amounts of air in a fluid-filled ME can restore some TM motion and hearing. We have developed a novel air-filled ME implant intended to act as a persistent air bubble and established that this implant is effective and suitable for implantation.
Methods and Materials: Implants were constructed of a thin multilayer polymer sandwich enclosing an air volume of 15-20 microliters. We tested implant (1) barrier properties by extended submersion in body-temperature saline; (2) acoustic properties by measuring acoustic impedance; (3) biocompatibility and bioinertness properties by implantation in chinchilla middle ears; and (4) effectiveness by measuring sound-induced umbo velocity in saline-filled human cadaver middle ears.

Results: (1) Implants remain inflated and fully functional after more than 2 years submersion. (2) They behave acoustically as an air bubble of slightly less volume than the implant. (3) They induced no inflammatory response and were not degraded by implantation of up to 18 months. (4) A single implant improves responses at frequencies below 1 kHz by up to 10 dB. If it contacts the TM, high-frequency response improves as well. Additional implants produce additional improvement.
Conclusions: These novel ME implants are biocompatible with good barrier properties, increase umbo velocity in saline-filled MEs, and should be able to restore some hearing in cases of otitis media. The implant seems appropriate for use in patients.
Funding from NIDCD

A1-5) A preliminary study of acoustic stimulation at the lateral canal.

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Background: Straightforward, reproducible acoustic stimulation of an anatomically easy accessible inner ear site is desired in subjects with profound mixed hearing loss. It could reduce surgical risks and possibly extend current indications of inner ear stimulation.
Methods: In this experimental study, the possibility of direct acoustic cochlear implant (DACI) stimulation of the intact, blue-lined and opened lateral semicircular canal (LC) was investigated and compared with standard oval window (OW) coupling. Round window (RW) velocity, as a measure of the performance of the device and its coupling efficiency, was determined in fresh-frozen human cadaver heads using a laser Doppler vibrometry setup. From these measurements, equivalent sound pressure level (LE) output was calculated.
Results: For the different conditions, velocity measurements were obtained in 6 heads and analyzed in three frequency ranges: low (0.1-0.8 kHz), middle (0.8-2.5 kHz) and high (2.5-8 kHz). With LC opened stimulation, a maximum LE of 126 equivalent dB SPL (SD = 10 dB) was reached, comparable to the standard oval window DACI position (127 dB SPL, SD = 21 dB). Pairwise comparisons revealed that RW velocity was significantly lower in the LC intact condition than in the standard OW condition in the low and middle frequency range, confirming the added value of direct acoustic inner ear stimulation. The effect of an induced stapes footplate fixation was also investigated. LE analyses showed no significant difference between LC opened and LC opened with stapes fixation conditions in the middle and high frequency ranges.
Conclusions: These preliminary results demonstrate for the first time that the LC may be a potential site for direct acoustic stimulation, even in case of stapes footplate fixation. Importantly, future intracochlear studies will need to address the impact on cochlear micromechanics and the vestibular system.

A1-6) Active middle-ear implant fixation in incus vibroplasty

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The active middle-ear implant Vibrant Soundbridge® (VSB) was originally designed to treat mild-to-severe sensorineural hearing losses. The Floating Mass Transducer (FMT) is crimped to the long incus process. The term incus vibroplasty is used to distinguish it from treatment in conductive and mixed hearing losses. Alternative fixation strategies have been developed including fixation at the incus body as well as new coupling elements to standardize energy transfer to the cochlea and avoid complications at the incus. The aim of this study was to functionally evaluate the attachment of the FMT to the incus in temporal-bone preparations and in clinical practice using coupling elements.
An extended antrotomy and a posterior tympanotomy were performed in ten fresh human temporal bones. As a control for normal middle-ear function, the tympanic membrane was stimulated acoustically and the vibration of the stapes footplate was measured by laser Doppler vibrometry (LDV). FMT-induced vibration responses of the stapes were then measured for standard attachment and for two types of SP-couplers (SP1 and SP2). Additionally, the functional outcome in two patients, provided with an SP2-coupler, was analysed two weeks and three months post fitting using pure tone audiometry, auditory thresholds for frequency-modulated (warble) tones, vibroplasty thresholds and speech audiometry in quiet and noise.

In temporal bone, LDV measurements showed significantly enhanced vibration amplitudes of the stapes footplate for the SP2-coupler compared with those for the standard attachment and the SP1-coupler. Average inter-individual amplitude variations were also smaller for the SP2-coupler. For the SP2-coupler, the clinical data of two patients with mild-to-severe sensory hearing loss showed low vibroplasty thresholds and convincing results for speech audiometry in quiet and noise. The attachment of the FMT to the short incus process, with the SP2-coupler, leads to enhanced mechanical and functional coupling in an experimental setup as well as in clinical practice.

A1-7) Comparison of alternative coupling methods of the Vibrant Soundbridge FMT

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Background: The active middle ear implant Vibrant Soundbridge provides a variety of coupling possibilities of the floating mass transducer (FMT) to treat patients with mild to moderate severe hearing losses. The FMT can be attached to the incus or positioned on the oval window using an oval window coupler or placed into the round window with or without a round window coupler.
Methods: For the retrospective analysis, 140 patients were selected with the FMT coupled to the incus (N = 61; bone conduction (BC) PTA(0.5 – 4 kHz) = 42.6), round window without a coupler (RW; N = 22; BC PTA(0.5 – 4 kHz) = 32.8), round window with a coupler (RWC; N = 23; BC PTA(0.5 – 4 kHz) = 37.2) or the oval window (OW; N = 34; BC PTA(0.5 – 4 kHz) = 36.7). Medians of aided word recognition scores (WRS; Freiburg monosyllable test) for different hearing loss groups (BC PTA(0.5-4 kHz) <30; 30 - <40, 40 - <50 and 50 - <60 dB HL) were compared for the different coupling types of the FMT.
Results: Similar WRS (median 90% or better) were found with all couplings for patients with a mean BC hearing loss up to 40 dB HL. For patients with a hearing loss between 40 and 50 dB HL, the median WRS was higher for the incus- and RWC-coupling (85%) than for the RW- and OW-coupling (70%). For a hearing loss between 50 and 60 dB HL, the median benefit was greatest for patients with the FMT coupled to the incus (85%), intermediate for the RW-coupling (70% without the coupler; 62% with the coupler) and lowest for patients with OW-coupling (40%).
Conclusion: The performance of the Vibrant Soundbridge FMT-couplings is equally good for patients with a mild hearing loss but differs for patients with greater hearing losses.

A1-8) Effects of loads and coupling techniques on the efficiency of the backward stimulation of the cochlea with the floating mass transducer

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Background: The round window vibroplasty has proved to be an effective treatment option for mixed and conductive hearing loss. Yet, the most efficient technique for the backward stimulation of the inner ear remains to be determined. Thus, in this human temporal study we investigated the efficiency of the backward stimulation of the cochlea with respect to the interposed material, the applied load and alignment of the floating mass transducer (fmt) to the round window membrane (rwm).
Methods: In seven fresh frozen temporal bones the fmt was placed against the fully exposed rwm by itself, with interposed cartilage, perichondrium and the round window coupler ® (rwc) (MedEl, Innsbruck, Austria). The fmt was pushed towards the rwm with increasing loads up to 200 mN by a load cell mounted on a translation stage. For each coupling condition the fmt was repositioned and the consecutive measurements repeated four times. The stimulation of the cochlea was measured by the volume velocities at the stapes footplate using LASER-Doppler-Vibrometry.
Results: The mean volume velocities revealed no significant differences depending on the interposed materials. Increase of loads of the fmt diminished volume veloc-

ities in the low frequency range. Furthermore, loads greater than 10 mN favored the stimulation of the cochlea in the high frequency range. In particular at minor loads, repositioning of the fmt lead to a considerable spread of the recorded volume velocities. However, the impact of a different alignment of the fmt gradually diminished with increased loads.
Conclusion: Perichondrium, cartilage and the rwc are similarly effective for the stimulation of the inner ear. The alignment of the fmt to the round window membrane represents a crucial prerequisite for optimal stimulation of the cochlea at minor loads. Applying high loads to the fmt predominantly impairs the backward stimulation of the cochlea.

Session A2

Topic: ME Biomechanics (I)

A2-1) Experimental investigation of the spatial motion of malleus and incus for sound induced vibrations

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Background: Acoustically stimulated the ossicular chain exhibits a frequency-dependent spatial motion. Previous studies indicate relative motion between the ossicles and flexibility of the middle ear joints. This study investigates the mobility of the incudo-malleolar joint (IMJ) and its role for the middle-ear sound transmission. Therefore a measurement setup for capturing the spatial relative motion between malleus and incus is presented.
Methods: Measurements on human temporal bones with intact middle-ear structures were performed. The spatial velocity of points on the incus and malleus under acoustic stimulation was measured with a 3D-LDV system. The orientation of the temporal bone relative to the 3D-LDV system varied in order to attain visible access to various locations on the ossicles. The spatial registration of all measurements points were obtained from combination of the positioning of the LDV system and micro-CT scans, performed subsequent to the velocity measurements. With the spatial velocities and the location of the measurement points, the rigid body motion of the malleus and incus and the relative motion within the IMJ were calculated. Error estimation was performed by comparison of the reconstructed and measured motion of the measurement points.
Results: The measurement setup was capable of capturing spatial motion of the IM complex. The IMJ is mobile in case of acoustic stimulation with the relative motion increasing with frequency. In the low frequency region the IM-complex motion is dominated by a rotational motion around the anterior-posterior axis.
Conclusion: The malleus and incus perform spatial vibrations when stimulated acoustically. Their motion and the relative motion within the IMJ can be captured by the presented measurement setup. The determination of the space coordinates of the measurement points and orientations of the specimen is crucial for the reconstruction of the spatial motion.

A2-2) Measurement of elastic properties of the stapes annular ligament using AFM technique

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Introduction: The elastic properties of the annular ligament (AL) of the stapes affect the stapes footplate (SF) displacement amplitude and thus directly affect the middle ear transfer function. Knowledge of the AL elastic properties (both stiffness and elastic modulus) is necessary for modeling of sound transmission from the middle ear to the cochlear fluid. However, due to measurement difficulties, the stiffness is generally estimated for each model. This leads to large differences in the obtained values.
The objective of this study is to measure the AL elastic properties in the physiological range of its deflection, i.e. for the SF displacements from 0 to ~100 nm.
Methods & Materials: Measurements were done on fresh cadaveric human AL specimens. An atomic force microscope (AFM) was used to mechanically load the AL and to record the load-deflection curves. The measurements were conducted for the SF displacements from 0 to ~100 nm. Based on these experimental curves, the AL stiffness was determined. The elastic modulus was estimated using the Kirchhoff-Love theory for thin plates.
Results: The measurement results showed that the AL is a linear elastic material, up to static deflections of about 100 nm, with a stiffness of about 120 N/m. The estimation of the AL elastic modulus gave value of about 1.1 MPa.
Conclusions: The AL elastic properties can be measured using the AFM technique that allows measurements in the nanometers scale. The obtained values for the stiffness and elastic modulus of the AL are intended to be used in numerical models of the human middle ear mechanics. Moreover, we plan to use these values to design a suitable membrane for a new chamber stapes prosthesis.

A2-3) Biomechanics of the incudo-malleolar joint - numerical and experimental investigations for quasi-static loads

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Background: Under large quasi-static loads, the incudo-malleolar joint (IMJ), connecting the malleus and the incus, is highly mobile. It can be classified as a mechanical filter decoupling large quasi static motions while transferring small dynamic excitations. This is presumed to be due to the complex geometry of the joint inducing a spatial decoupling between the malleus and incus under large quasi-static loads.
Methods: Spatial Laser Doppler Vibrometer (LDV) measurements on isolated malleus-incus-complexes (MICs) were performed. With the malleus firmly attached to a probe holder, the incus was excited by applying quasi-static forces. Both the application point and the direction of the force were varied during the measurement. For each of them the resulting displacement was measured subsequently at different points on the incus using a 3D-LDV system. The location of the force application point and the LDV measurement points were calculated in a post-processing step combining the position of the LDV points with the CT data of the MIC. The rigid body motion of the incus was then calculated for each force application point. A numerical model of the IMJ was derived, with the joint geometry implemented using a contact formulation. The loading of the joint surfaces for different configurations was calculated.
Results: The static loads result in a spatial motion of the incus. The direction of the motion changes with the direction of the excitation of the incus. Such kinematic is defined by the geometrical features of the IMJ. The load maps show a kinematic guidance of the incus with the geometry of the IMJ.
Conclusion: Quasi-static measurements of the IMJ support the hypothesis of the IMJ being a mechanical filter. The contact formulation needs to be included in mathematical simulation of the IMJ in order to describe kinematics of the IMJ adequately.

A2-4) A single-ossicle ear: acoustic response and mechanical properties measured in duck

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The middle ear of birds only contains a single ossicle, the columella, while the hearing threshold in birds is comparable to mammals. In humans, damaged ossicles are often replaced by a prosthesis that directly connects the eardrum to a hole in the stapes footplate. These prostheses, however, can experience undesired extrusions when exposed to large quasi-static pressures. Understanding the avian ME mechanics will give insight in nature's solutions and may reveal the optimal characteristics of a single-ossicle ear. In this work, the acoustic response of the avian middle ear and the mechanical properties of the eardrum are studied with optical interferometry and finite element modeling.
Under acoustic stimulation, the full-field displacement of the lateral eardrum surface of a dissected duck's ear is measured with stroboscopic holography experiments. The middle ear transfer function is obtained with laser Doppler vibrometry by measuring the single-point velocity of the ossicle at different positions. Next, a finite element model is created to simulate the system's acoustic response. Geometry information is obtained from stained µCT-measurements.
In the model, a sensitivity analysis is performed to determine the relative influence of the viscoelastic parameters on the system's acoustic response. Then, the most relevant mechanical parameters, such as the eardrum elasticity, are obtained through reverse engineering by optimizing the model output to the experimental outcome in a surrogate modeling routine. We will report on measurement results of the acoustic response and transfer function of the duck middle ear and on eardrum elasticity parameters.

Session A3

Topic: ME Biomechanics (II)

A3-1) Superior Semicircular Canal Dehiscence (SSCD): temporal bone experiments and clinical symptoms

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Background: A multitude of specific and unspecific ear symptoms are related to a dehiscence of the superior semicircular canal in CT-scans. Amongst others, a significant conductive hearing loss, said to mimic an otosclerotic stapedial fixation,

is of interest from a biomechanical point of view. Experimental data from temporal bone and animal studies to confirm this pathomechanic correlation of
a “third window” are contradictory.
Methods: We measured the transmission of sound energy in 10 fresh temporal human bones before and after opening the superior semicircular canal under water and simulating its correct
position in vivo with coverage by dura and water.
Results: Opening the canal against air resulted in a loss of sound transmission of maximal 10-15 dB only in frequencies below 1 kHz. No significant deterioration occurred in the mid- and high frequencies. When covering the dehiscence with a dura patch, the transfer function normalized.
Conclusion: The results of our experiments with the opening towards air are in agreement with the data reported by most of the other laboratories. Moreover, the normalization of the transfer function with the dura coverage, which resembles the condition in vivo more closely, does not support the concept of an extensive and clinically considerable conductive air conduction component. A dehiscence, which is suspected in a CT, does not imply a contraindication to a middle ear surgery for a conductive hearing loss. Careful consideration of the value of diagnostic tools and, especially, keeping in mind the multitude of different causes of the unspecific symptoms, as they were recognized by otologists from the pre-CT-era, is advocated and will be discussed in the presentation.

A3-2) Motion of tympanic membrane in guinea pig otitis media model investigated by scanning laser vibrometry and finite element modeling

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Introduction: Otitis media as an inflammatory or infectious disease leads to the loss of ossicular mobility and increases the complexity of tympanic membrane (TM) motion. However, the full-field TM motion changes induced by two otitis media: acute otitis media (AOM) and otitis media with effusion (OME) in animal models have not been quantified in the literature. This paper reports the full-field motion of the TM measured by scanning laser Doppler vibrometry (SLDV) and simulated by a finite element (FE) model of guinea pig ear.
Methods: The AOM and OME were created by transbullar injection of streptococcus pneumonia type 3 and lipopolysaccharide in 6 and 4 guinea pig ears, respectively. 6 ears without treatment served as control. The TM surface motion under normal and diseased conditions was measured by using SLDV across the frequency range of 0.2 to 40 kHz. The displacement-frequency curves at the umbo and four quadrants were further extracted from the SLDV results for comparison purpose. A 3D FE model of the guinea pig ear was developed based on micro-CT images and used to simulate the SLDV measurement.
Results: The SLDV results of normal ears showed a simple deflection pattern with the displacement peak about 0.01 µm/Pa at low-medium frequencies while the complex pattern with large number of maximum appeared at higher frequencies. The effusion reduced the displacement peak and resulted in more complicated TM vibration pattern at low frequencies. The FE model-derived results were compared with the measurement data from the normal and otitis media ears, and a general agreement was observed.
Conclusions: This is the first study on TM surface motion in two types of otitis media in which both SLDV measurements and FE modeling results are compared. These two approaches provide more insight into sound-induced TM vibration in diseased ears.

A3-3) Mechanical damage of tympanic membrane in relation to impulse pressure waveform – a study in chinchillas

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Introduction: Mechanical damage to middle ear components in blast exposure directly causes hearing loss and the rupture of tympanic membrane (TM) is the most frequent injury of the ear. The severity of injury graded by different patterns of TM rupture is related to the overpressure waveform generated, such as the free-field or shock tube waves vs. the Friedlander waves or complex waves. In this paper, we report the preliminary study on relationship between the TM rupture threshold and the impulse or overpressure waveform in animal model of chinchilla.
Methods: A compressed nitrogen-driven blast apparatus located inside the high intensity sound chamber in our lab was used for this study. Eighteen young adult chinchillas were divided into two groups: one group was exposed to blast in “open field” and another group was exposed to blast with a shield covering the animal head. A pressure sensor was placed at the entrance of the ear canal. The ABR and wideband tympanometry were measured before and after exposure to determine the changes of hearing threshold and middle ear function.
Results: The TM rupture threshold, damage pattern, and pressure waveform were recorded. The TM damage patter varied with overpressure level and the rupture threshold in

shielded case was lower than that in open field (182 vs. 190 dB SPL). The impulse pressure energy spectra analysis for the open and shielded waveforms showed different energy distribution over octave frequency bands. The tympanometry measurement well reflected the middle ear function change and the ABR results showed 10-30 dB of threshold shift from the pre-exposure baseline at high frequencies.
Conclusions: The TM rupture threshold difference between the open and shielded cases suggests that the acoustic role of helmet may exist, which intensifies ear injury during blast exposure. However, further study on characterization of damage and energy flow is needed.

A3-4) Motion of tympanic membrane surface produced by reverse mechanical stimulation

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Background: The motion of the tympanic membrane (TM) induced by sound stimuli presented to the ear canal (forward sound) has been described by our group as a combination of primary stationary waves and smaller traveling-wave-like components. Motion of the TM produced by mechanical stimulation of the ossicles (reverse mechanical) has not been well studied, but its description can improve our understanding of the biomechanics of the TM.
Methods: We used stroboscopic holographic interferometry to quantify surface motion of the TM produced by reverse mechanical stimulation of the incus (via a piezoelectric device) in normal human temporal bones. An artificial ear canal of 'natural' dimensions was used to mimic the natural human ear canal while providing a view of the TM for holographic measurements. Stimuli were continuous sinusoids between 0.2 and 18 kHz at levels chosen to produce measurable motions of the TM.
Results: Compared to forward sound stimulation, TM motions produced by reverse mechanical stimulation showed more prominent traveling waves along the TM surface. These waves generally travel from the manubrium towards the TM periphery, consistent with the TM being driven by a localized mechanical stimulus. Surprisingly, the motion along the manubrium was generally lower than in other areas of the TM, consistent with the conical shape of the TM acting like a "catenary", also suggesting that TM surface motion could be related to local TM mechanical properties. At some frequencies, motion of the TM on one side of the manubrium was anti-phasic with motion of the other, consistent with an asymmetry in the TM structure or the ossicular stimulus.
Conclusion: TM motions produced by reverse mechanical stimulation showed clear differences from motions induced by forward sound stimulation. Quantification of traveling waves along different TM surface areas can help infer location dependent variations in TM mechanical properties.

A3-5) On the connection between the eardrum and the malleus: a detailed study through micro-CT and histology

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Introduction: The manubrial fold, a soft-tissue connection between the eardrum and the manubrium of the malleus, is a delicate structure in the human middle ear that is not observed in other mammals. Its properties may have a substantial influence on the mechanics of the middle ear (De Greef 2014, Hoffstetter 2010), emphasizing the importance of morphologic and mechanical knowledge of the fold. Additionally, detailed insight into the histology of the structure will be valuable for the further development of implantable eardrums. Literature features inconsistencies and debate regarding the properties of the manubrial fold. Given the possible importance of this structure, this uncertainty hinders the full comprehension of middle ear mechanics and the construction of highly realistic and reliable computer models.
Materials & methods: We collect 10 samples, consisting of only the malleus, the eardrum, the annular ring and a some ear canal epithelium. First, unstained micro-CT scans (Bruker Skyscan 1172, voxel pitch: 3.36µm) are acquired. Secondly, the samples undergo standard preparation steps for histologic sectioning. The micro-CT datasets are used to measure morphologic parameters of the manubrial fold, while histologic sections are used to investigate the histologic characteristics.
Results: The µCT dataset of the first sample enables the

extraction of multiple morphologic parameters. The anterior-posterior width of the MF in the first sample ranges from (496 ± 10) µm to (733 ± 10) µm along the manubrium, in disagreement with descriptions of it as an extremely thin fibrous layer or fold (Graham 1978, Gulya and Schuknecht 1995). Histologic preparation of the sample is not finished at the present time. Work is ongoing, and at the conference, full results will be available and presented.
Conclusions: The combination of micro-CT and histology enables us to construct detailed morphologic models of the manubrial fold, and to determine tissue parameters. This knowledge will help constructing realistic mechanical middle ear models.

A3-6) Response of the human tympanic membrane to transient acoustic and mechanical stimuli

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Introduction: Though most characterizations of tympanic membrane (TM) response have used steady-state tonal stimuli, most environmental sounds are transient in nature. In addition, there is an ongoing debate about how different parts of the TM contribute to sound transmission to the middle ear with low or high frequency stimuli. Here we investigate the response of the TM to global (acoustic clicks) and local transients (mechanical impulses) at various locations on the umbo and TM.
Methods: Lightly-fixed (Thiel) human temporal bones were prepared by removing the ear canal, inner ear, and stapes, leaving the incus, malleus, and TM intact. Motion of the entire TM was measured by a digital holography system with a high speed camera at rates up to 87 500 frames per second, giving a temporal resolution of <23 µs for the duration of the TM response. Acoustic clicks and mechanical impulses in response to a 50-usec square voltage pulse were delivered by a loudspeaker or a small piezoelectric stack.
Results: The entire TM responds nearly instantaneously to acoustic transient stimuli, though the dominant response frequency and time constant of decay vary with location. With local mechanical transients, the TM responds first locally at the site of stimulation, and the response spreads approximately symmetrically and circumferentially around the umbo and manubrium.
Conclusions: Acoustic and mechanical transients provide distinct and complementary stimuli for the study of TM response. Spatial variations in dominant frequency, decay, and rate of spread of response imply local variations in TM stiffness, mass, and damping. Knowledge of these TM mechanical properties can influence the design of TM and ossicular prostheses.
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A3-7) Sound transmission via the malleus-incus complex

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Background: The malleus-incus complex (MIC) plays a crucial role in the hearing process as it transforms and transmits acoustically-induced motion of the tympanic membrane, through the stapes, into the inner-ear. However, the transfer function of the MIC under physiologically-relevant acoustic stimulation is still under debate, especially due to insufficient quantitative data of vibrational behavior of the MIC. This study focuses on the investigation of the sound transformation through the MIC, based on measurements of three-dimensional motions of the malleus and incus with full six degrees of freedom (6 DOF).
Methods: The motion of the MIC was measured in three cadaveric human temporal bones with intact middle-ear structures excited via a loud speaker embedded in an artificial ear canal, in the frequency range of 0.5-5 kHz. Three-dimensional (3D) shapes of the middle-ear ossicles were obtained by sequent micro-CT imaging, and an intrinsic frame based on the middle-ear anatomy was defined. All data were registered into the intrinsic frame, and rigid body motions of the malleus and incus were calculated with full six degrees of freedom. Then, the 3D transfer function of the MIC, defined as velocity of the incus lenticular process relative to velocity of the malleus umbo, was obtained and analyzed.
Results: Based on the transfer function of the MIC, the motion of the lenticularis relative to the umbo reduces with frequency, particularly in the 2-5 kHz range. Analysis of the individual motion components of the transfer function indicates a predominant medial-lateral component at frequencies below 1 kHz, with low but considerable anterior-posterior and superior-inferior components that become prominent in the 2-5 kHz range.
Conclusion: The transfer function of the human MIC, based

on motion of the umbo and lenticularis, have been visualized and analyzed. While the magnitude of the transfer function decreases with frequency, its spatio-temporal complexity increases significantly.

A3-8) The impact of a cochlear implant electrode array on middle ear transfer function

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Background: As a treatment for partial deafness with residual hearing in the lower frequency range the combined acoustic and electric stimulation of the cochlea has become widely spread. The acoustic stimulation is provided by a hearing aid's air-borne sound and the electric stimulation by a cochlear implant electrode array, which may inserted through the round window or a cochleostomy.
Methods: With regard to a most efficient acoustic stimulation of the cochlea we investigated the influence of 4 different intracochlear electrode arrays as well as their insertion paths on middle ear vibration transmission. Furthermore the influence on inner ear fluid dynamics has been evaluated in 6 non fixated human temporal bones. Therefore the stapes footplate and round window membrane movements were measured with laser vibrometers in response to an acoustic stimulation at the tympanic membrane.
Results: The results show a small trend towards an increase of the oval window net volume velocities with a present cochleostomy. The footplate rotational component along the long axis increases by trend independent of electrode array geometry and insertion path while the volume velocity ratio of round and oval window remains unchanged within standard deviations of measurements. Nearly all changes of middle and inner ear transfer functions were insignificant.
Conclusion: It can be concluded that the investigated intrachochlear electrode arrays do not change middle and inner ear mechanical properties to a point of clinical relevance independent of electrode type and insertion path.

Session B1

Topic: Computational Models

B1-1) Testing the effects of variations in human tympano-ossicular chain geometry and material properties on middle-ear sound transmission using 3D finite-element models

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Introduction: Unique features of the mammalian middle ear include a flexible three-bone ossicular chain and radial and circumferential collagen-fiber layers in the eardrum. To study the implications of these features on middle-ear function, a series of 3D finite-element models were created and used to simulate the middle-ear pressure gain (GME) from the ear canal to the cochlea: Pc/Pec.
Methods: An anatomically accurate finite-element model of the human ear canal and tympano-ossicular chain was generated in COMSOL using µCT data. The geometry was then progressively simplified to include a circular flat or conical eardrum and columella-like ossicles. The properties of the eardrum were varied between a soft isotropic material and a material with increased stiffness in either the radial direction, circumferential direction, or both to simulate various arrangements of collagen fibers. The cochlea was represented as a resistive load.
Results: For the flat eardrum with a cylindrical ear canal and columella, the response is poor above 1 kHz. Replacing the eardrum with a cone improves the response above 1 kHz by up to 40 dB or more, especially when both radial and circumferential fiber layers are present. Combining a natural ear canal and eardrum with a columella generally performs worse than the cone, but still much better than the flat eardrum. The fully natural case performs similarly to or better than the cone and columella at high frequencies and features an additional 0.2–2.5 kHz boost.
Conclusions: An anatomically accurate or conic eardrum performs much better than a flat eardrum, and a natural ossicular chain appears to improve the mid-frequency response over a columella-based middle ear. Combining radial and circumferential fibers in the eardrum improves the high-frequency response over just having radial fibers, while just having circumferential fibers performs poorly.

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B1-2) Modelling of cochlear hydrodynamics before and after stapedotomy using new FSI model

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Background: Various diseases of middle ear, for example otosclerosis, lead to conductive hearing loss. Piston stapes prostheses are commonly implanted in stapedial otosclerosis to stimulate the perilymph and to restore hearing. However, cochlear hydrodynamics after the piston-stapedotomy may differ significantly from the normal state.
The objective of this study is to assess the effect of stapedotomy on: (1) the basilar membrane (BM) vibration and (2) the pressure wave propagation in perilymph in scala vestibuli (SV) and scala tympani (ST).
Methods: A 3D Fluid-Structure-Interaction (FSI) model of the cochlea was built and validated based on experimental data. The frequency-dependent displacement amplitudes of the stapes footplate and the piston were used to excite the model. The FSI analysis was conducted for 2.5, 5 and 10.0kHz). The BM vibrations and the perilymph pressure oscillation in the normal (pre-stapedotomy) state were compared with the literature data. Then, the above parameters were analyzed for the post-stapedotomy state.
Results: The passive BM vibration for the pre- and post-stapedotomy state is consistent with our previous FE study and with the published data. We observed a significant decrease in the BM response caused by the piston. Similarly, the amplitude of perilymph pressure oscillation in the SV and the ST was significantly reduced. In all frequencies, the FSI model-predicted the temporary differential intracochlear pressure for the piston stimulation near 20dB lower than for the SF stimulation.
Conclusions: The stapedotomy can be well simulated by our new FSI model to predict the postoperative auditory outcomes. Cochlear hydrodynamics, especially the differential perilymph pressure, derived from the FSI model may be used to analyze the effectiveness of cochlear stimulation by various middle ear prostheses or by round window.

B1-3) On the influence of anatomical variations on METF - theoretical investigations using a finite element model

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Background: Measurements of the middle ear transfer function (METF) of human temporal bone preparations show a great inter-individual variance. It is widely accepted that the individual shape of the middle ear structure affects the METF however its detailed influence has not been completely clarified. The aim of this study is to determine the effect of middle ear morphology on the METF and to differentiate it from the influence of varying material properties.
Methods: We built a parametric finite element (FE) model based on microscopic measurements on a representative middle ear, which comprises the outer ear canal, the tympanic membrane, the ossicles and a reduced model of the cochlea. The model can be adapted to different individual middle ear morphology by using distinctive points and dimensions derived from digital volume tomography (DVT) images.
In this study we used the imaging data of ten temporal bone preparations, consisting of seven DVT and three Micro-CT images, to calculate their particular METFs. Among these were also specimens with partial ossicular replacement prosthesis (PORP). For those also measured METF of the intact ossicular chain were available. The derived METFs were compared to the measured ones and literature data.
Results: The calculated METFs show similar inter-individual variations as the measured ones, but do not exactly match. The remaining difference can be attributed to uncertainties such as the acquisition of the coordinates of the distinctive points, variations in the material properties and anatomical parameters that were not adapted, like the thickness of the tympanic membrane.
Conclusion: Anatomical variations can reproduce the main variations of the METF. The possible reasons for the remaining differences between calculated and measured METF need to be further evaluated.

B1-4) Precision of ossicular motion reconstructed from 1D and 3D-LDV measurements

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Background: To experimentally capture the middle-ear transfer behavior, a well-established method is to measure the motion of the ossicles with one-dimensional Laser-Doppler-Vibrometers (1D-LDV) and reconstruct the ossicular motion with reduced degrees of freedom. Many results from such measurements can be found in literature. However, it is known that the ossicular chain vibrates with very complex spatial patterns which may influence the results from the 1D-LDV measurements. The aim of this contribution is to assess the precision of motion reconstructed from 1D-LDV measurements in comparison with fully three-dimensional measurements using a 3D-LDV system.
Methods: Spatial Laser Doppler Vibrometer velocity measurements on two human temporal bones with intact middle-ear structures were performed for acoustic excitation. The rigid body motion was reconstructed for all six degrees of freedom and the geometry was identified by micro-CT scans. With rigid body motion and geometry known, it is possible to calculate motions at all points of the ossicles. From these data, virtual 1D-LDV measurements were extracted and the reconstruction of motion was performed with reduced degrees of freedom. The reconstruction from the virtual 1D-LDV was compared to the spatial reconstruction with all six degrees of freedom.
Results: The reconstruction with reduced degrees of freedom, reconstructed from 1D-LDV measurements shows differences to the full spatial reconstruction. The 1D-LDV measurements cannot identify all spatial motion components contributing to the measured data, hence biasing the reconstructed motion. These errors depend on the alignment of the 1D-LDVwith respect to the desired reconstruction axis or plane, as well as on the choice of measurement points.
Conclusion: Precise reconstruction of the ossicular chain motion requires 3D-LDV measurements. When a 1D-LDV system is used, appropriate alignment and measurement points have to be chosen and measuring the same ossicle from different angles is necessary, even for the case that only a subset of spatial motion components is of interest.

B1-5) Statistical shape modeling of the incudomalleolar complex using micro-CT and clinical cone-beam CT

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Introduction: A large variation in material properties and geometry exists in the human temporal bone. These variations can affect hearing and middle ear sound transmission. Middle ear computer (finite element, FE) models are successfully used to predict sound transmission and its dependence on material properties. The model geometry, however, is mostly based on data of a single sample. Here we use statistical shape models (SSM) to characterize the natural anatomical variations present in the incudomalleolar (IM) complex of humans. SSM can later be used in FE models to study the effect of geometry on sound transmission, or parameters can be fitted to clinical CT data to obtain a patient-specific computer model.
Methods and Materials: In this study we combine data of high resolution micro-CT scans (uCT, 20 um resolution) of 6 human cadaveric temporal bones and clinical cone-beam CT scans (CBCT, 150 um resolution) of 100 patients. First, a dense correspondence between the uCT samples is obtained by pair-wise elasticity modulated registration of a reference sample to each of the remaining samples. A SSM is built from these corresponded scans using principal component analysis (PCA), describing the average shape and the main variations of the middle ear within the uCT population. Next this SSM is fitted to clinical CBCT data by elastic registration with the SSM as shape prior.
Results and conclusions: We will obtain an average geometrical model for malleus, incus and IM complex and characterize the deviations present in the patient population. We will do this by reporting natural variation of size and thickness of malleus head, neck and manubrium, the long and short process of the incus and relative angles in the IM complex.

B1-6) Virtual reality in ear surgery 2015 and beyond.

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The role of virtual simulators in training for ear surgery is growing as human temporal bones and scheduled tutor resources are becoming increasingly sparse. A number of ear surgery simulators offers haptic drilling of a bony voxel model, but in the new VES versions even the soft tissues are rendered interactive as deformable surface models.
You may download the Visible Ear Simulator VES versions 1.3 and 2.2 as academic freeware from the website http://ves.cg.alexandra.dk, install it on any PC with a GeForce GTX graphics card and test it with just a PC mouse.
Operation with a Phantom Omni©/ Geomagic Touch© haptic device of the high-fidelity simulator provides intuitive 3-D handling with force-feedback and drilling in real-time with a Chinese, English or German language interface and pdf manuals. An integrated surgical tutor provides stepwise instructions through conventional images and brief texts during drilling. Metrics derived from the bony segment of the corresponding steps are used to color-code the volumes of bone to be removed directly on the 3-D model and to provide immediate feedback and final evaluations. The latest VES version 2.2 accepts haptic devices with FireWire, Ethernet- or USB interface, and includes interactive deformable representations of the Dura, Sinus, Facial nerve, Chorda, acoustic-vestubular

nerve, Drum and Skin. This version will soon offer a selection of interactive cholesteatomas and neuro-otologic scenarios. Partnership projects are developing CT/MRI import functions for patient specific scenarios, and haptic simulation of CI electrode insertion and general device handling.

Session B2

Topic: ME Active Implants (II)

B2-1) Efficiency of the Codacs™ actuator in alternative stimulation applications of the stapes

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Background: The intended use of the Cochlear's Direct Acoustic Cochlear Implant (Codacs™, Cochlear Ltd.) actuator is the stimulation of the inner ear through the stapes footplate (SFP) with a K-Piston. Here the actuator efficiency in stimulation of the stapes head and the SFP was investigated.
Methods: Beside the standard K-Piston application (N = 11) three alternative stimulation sites were tested with the Codacs™ in cadaveric human temporal bones. Prior to the standard K-Piston application (N = 9) the stapes head was stimulated with a "Bell prosthesis" (N = 9) and the stapes footplate (SFP) with an "Omega connector" (N = 8). During stimulation the axial coupling force was adjusted to ~ 5 mN compared to the standard application with no static loading force. Using a Laser Doppler Velocimeter the round window membrane (RW) displacements in response to the stimulation served as reference for output determination.
Results: Between 0.125 and 10 kHz the average outputs in all conditions were flat within a range of maximally 23.5 dB, usually having a peak at the actuator resonance (approx. 2 kHz). Both stimulation modalities using the stapes as input site generated similar output and were significantly more efficient compared to the standard K-Piston application. Using the RW displacement as reference, the determined mean (0.5, 1, 2, 3, 4 kHz) equivalent sound pressure output levels [eq. dB SPL] at 1 VRMS input voltage, were 133 (Bell), 134 (Omega) and 115 eq. dB SPL (K-Piston).
Conclusions: Stimulation of the stapes footplate provided significant higher output than the standard K-Piston application when performed at controlled axial force. Our results confirm that the Codacs generates sufficient output at alternative stimulation sites, provided that experimental conditions are adapted to the "real" situation including geometric adaptation and control of axial force pre-load.

B2-2) Electroacoustical model of floating-mass transducer stimulation of the middle ear

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Background: In the last years, a considerable variety of attachment methods for active middle-ear implants of the floating-mass type have been presented. Properties and mutual advantages and disadvantages of these methods have been typically investigated in temporal-bone experiments or directly in patients. However, analysis in terms of physical models has been lacking.
Method: We develop an electro-acoustical two-port model describing the electrovibrational transfer characteristics of a floating-mass transducer (FMT) implanted to the middle ear. It consists of masses of the floating mass and its housing, stiffness and damping of the internal suspension of the floating mass, the resistance and the turns of the coil. As a termination, we add stiffness of the annular ligament and resistance of the cochlea.
Results: The model explains key characteristics of temporal-bone experiments such as the 18 dB/oct slope of the voltage-to-stapes velocity transfer function at low frequencies and shows that the asymptote of -18 dB/oct to the high-frequency part of the transfer function as well as the minimal phase excursion seen in individual experimental data can only be explained by introducing an additional stiffness term accounting for the non-rigidity of the attachment of the FMT to the middle-ear ossicles. Reasonable estimates of the parameter values lead to a fairly accurate replication of the experimental transfer function.
Conclusion: A relatively simple and self-contained electro-acoustic model can account for most of the characteristics of the FMT implanted to middle-ear structures, and might be well suited for designing of different attachment sites and methods in the middle ear.

B2-3) Evaluation of coupling conditions of an active middle ear implant (Vibrant Soundbridge) using laser-doppler vibrometry in vivo

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Background: The keypoint during implantation of an active middle ear implant is the coupling of the electromagnetic transducer to a vibrating part of the ear, i.e. the middle ear or the cochlear windows. A largely non-dissipative and stable transmission of sound is the requirement for a sufficient amplification and hearing without distortion. However the surgeon's chance to control these criteria is limited. Therefore the success of a middle ear implantation is mainly determined by the experience of the surgeon. In some cases there are deteriorations of aided thresholds over time -either spontaneously or induced by a magnetic resonance tomography (MRT) examination. CT scan or digital volume tomography (DVT) can only provide limited information about possible transducer dislocations and an opening of the middle ear cavity could become necessary.
Method: In both cases the use of a Laser-Doppler-Vibrometer (LDV) enables the extraction of necessary information. The LDV is an established method within the middle ear research and allows the measurement of displacements down to a few nanometers. The laser beam may be coupled to a surgical microscope and is targeted to the structure of interest by a joystick, e.g. the tympanic membrane. Now the vibrating ossicular reconstruction prosthesis (VORP) is actuated by the audiometric fitting software to measure the transfer function and its deviation from the normal group.
Results: We present the possibilities of testing the coupling conditions of middle ear implants during surgery. Additionally we developed a method to control the applied vibrations postoperatively by measuring ear-drum deflections using an electrically tunable lens which substitutes the use of a surgical microscope.
Conclusions: LDV enables the control of coupling active middle ear implants to the ears of patients to improve hearing. Newly developed hardware may substitute the use of a microscope especially for fitting middle ear implants post operatively.

B2-4) Fully implantable hearing aid in the incudostapedial joint gap

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Background: A fully implantable hearing aid is introduced which is a combined sensor-actuator-transducer for insertion inside the incudostapedial joint gap. The active elements each consist of a thin titanium membrane with an applied single crystal piezo. The effectiveness of the operating principle is verified in a temporal bone study. We also take a closer look on the influence of implantation-induced annular ligaments stiffening on the transducers output.
Methods: An assembly of the transducer with 1.2 mm thickness is built and inserted into four temporal bones. For two of the temporal bones the incudostapedial joint gaps has been extended by up to 0.5 mm with a CO2 pulse laser. Thus different annular ligament stiffening can be examined. The tympanic membrane is stimulated with a broadband multisine sound signal in the audiological frequency range. The movement of the stapes footplate is measured with a laser Doppler vibrometer. The sensor signal is digitally processed and the amplified signal drives the actuator. The resulting feedback is minimized by an active noise control least mean square (LMS) algorithm which is implemented on a field programmable gate array. The dynamic range and the functional gain of the transducer in the temporal bones are determined. The influence of the size of the joint gap is evaluated with a Finite Elements Model (FEM) of the middle ear.
Results: In the frequency range above 1 kHz a functional gain of 30 decibel and above is achieved. This proposes the transducer as a potential treatment for moderate to severe high frequency hearing loss. The precondition for these results is a reduced tension on the joints and ligaments.
Conclusion: The transducer offers sufficient good results for a comprehensive application. Adaptions in the transducer design or chirurgical approach are necessary to cope with ligament stiffening issues.

B2-5) Importance of controlled static contact force in mechanical round window stimulation

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Objective: The round window (RW) stimulation is successfully done with middle ear implants. But clinical studies show a substantial degree of variability. We stimulated the round window with the investigational device Direct Acoustic Co-

chlear Stimulator Partial Implant (DACS PI, Phonak Acoustic Implants SA) and the Vibrant Soundbridge (VSB). The aim of our study was to analyse the impact of static force pretension on efficiency and repeatability of sound transmission via the RW.
Methods: The reachable range and maximum equivalent sound pressure (ESP) output of RW stimulation was investigated in temporal bones (TB). The stimulation was performed using prostheses with a sphere-shaped tip. The ESP level was determined at the tympanic membrane. The static contact force was varied in the range 0 to > 50 mN with the DACS PI and was kept constant at 2 mN with the VSB.
Results: We analysed the data of 18 TBs experiments (10 TBs DACS PI, 8 TBs VSB). Comparison of sound evoked stapes footplate vibration with DACS PI driven vibration at moderate loading force (4 mN) lead to an average sound ESP level of approx. 103-120 eq. dB SPL @ nominally 1Vrms input for frequencies ≤ 4 kHz with a roll-off at higher frequencies (6 - 10 kHz). The VSB obtained an ESP output at constant pretension of 97 – 107 eq. dB SPL (0.5 – 10.0 kHz, @ nominally 1Vrms to the actuator). The output efficiency was monotonously growing with applied contact force using the DACS PI. The inter-individual variation was significantly reduced combining the coupler with an interposition at constant force using the VSB.
Conclusion: We demonstrated that the static force in round window stimulation is fundamental for stimulation efficiency and independent of the used actuator. We could decrease the variability between different preparations and improve the repeatability by controlled static force.

B2-6) Mechanical stimulation of the umbo using a light-activated contact hearing device: Maximum equivalent pressure output and maximum stable gain measurements in temporal bones and model calculations

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Background: The non-surgical Contact Hearing Device (CHD) consists of a light-activated balanced-armature tympanic-membrane transducer (TMT) that drives the middle ear through contact with the umbo, and a behind-the-ear unit with a widely vented Light-Emitter Assembly inserted into the ear canal that encodes amplified sound into pulses of light that drive and power the TMT. In comparison to acoustic hearing aids, the CHD is designed to provide higher levels of maximum equivalent pressure output (MEPO) over a broader frequency range and a significantly higher maximum stable gain (MSG).
Methods: No artificial middle-ear model yet exists for testing the CHD, so we instead measured it on fresh human cadaveric temporal bones. To calculate the MEPO and MSG, we measured the pressure close to the eardrum and stapes velocity for sound drive and light drive using the CHD. The measurements of MEPO and MSG are compared with calculations from a circuit-model (O'Connor and Puria, 2008).
Results: The baseline sound-driven measurements are consistent with previous reports in temporal bones. The average MEPO (N=4) varies from 116 to 128 dB SPL in the 0.7 to 10 kHz range, with the peak occurring at 7.6 kHz. From 0.1–0.7 kHz, it varies from 83 to 121 dB SPL. For the average MSG, a minimum of about 10 dB occurs in the 1–4 kHz range, above which it rises as high as 42 dB at 7.6 kHz. From 0.2 to 1 kHz, the MSG decreases linearly from about 40 dB to 10 dB. Model calculations and measured results are in general agreement for MEPO while there are significant differences in the MSG above about 3-4 kHz indicating a need for model improvements in backward transmission.
Conclusions: The CHD investigational device may offer a way of providing broad-spectrum amplification appropriate to treat listeners with mild-to-severe hearing impairment.

B2-7) Stapes velocities and intracochlear pressures for two modes of direct mechanical stimulation

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Introduction: A study was performed in human temporal bones comparing output of two middle ear direct stimulation devices developed by Cochlear Limited, the Codacs and T2 actuators. Responses are compared for stimulation of the cochlear fluid directly via an Aerial actuator extension through a stapedotomy, and for direct contact with the incus body by the T2. Round window (RW) membrane velocity and intracochlear (IC) pressures were measured and compared across transducers.
Methods: A posterior tympanotomy was performed to expose middle ear structures. Scala vestibuli (SV) and tympani (ST) were blue-lined, and a ~300 µm cochleostomy made with a fine pick. Fiber-optic pressure probes were inserted ~100 µm into each cochleostomy using stereotaxic micromanipulators. After experiment completion, each specimen was dissected to confirm correct pressure probe placement.

Results: When the Codacs and T2 are applied in a similar manner, i.e. with a piston through a stapedotomy, responses were comparable for the two actuators: RW velocity was ~15 dB and intracochlear pressures were ~5 dB higher across frequency for Codacs. T2 stimulation of the incus body yielded RW velocities and IC pressures that were higher than stimulation through the stapedotomy by either actuator. Codacs stimulation was sensitive to insertion depth, with responses increasing with stapes piston depth in the stapedotomy.
Conclusions: These results have several implications for transducer development. First, results indicate that the Codacs slightly out-performs the T2 with stapes piston stimulation. Second, Codacs stimulation was substantially affected by insertion depth, which has important implications for surgical guideline development. Finally, results suggest that the T2

actuator's mechanical impedance is better matched to the ear's impedance at the incus body than it is to the cochlea directly through a stapedotomy. This effect warrants further exploration, and may have important implications in patient candidacy, particularly for cases of severe sensorineural hearing loss.
Funding: NIDCD: 1T32-DC012280 (NTG)

B2-8) Comparison of audiological results of the Bonebridge to a percutaneous device

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Background: In conductional, mixed hearing losses and single-sided-deafness bone anchored hearing aids are well established treatments. Transcutaneous transmission across the skin avoids the percutaneous abutment and the risk of infections and requires less care. In this study audiological results of the transcutaneous bone conduction instrument Bonebridge (MED-EL) were compared to a generally used percutaneous device.
Methods: Ten patients from the ENT department at the Medical University Hannover, with a transcutaneous hearing instrument, were audiologically compared to the results of ten matched patients with a percutaneous device. All patients fulfilled the audiological criteria for both devices (BC ≤ 45 dB HL at 0.5, 1.0, 2.0, 4.0 kHz) and had > 8 weeks of experience with the respective device. Patients with single-sided-deafness were excluded from the study. Tests included AC and BC thresholds with headphones, unaided and aided thresholds in sound field. The speech intelligibility was determined with speech from the front (S0) using the Freiburg monosyllable test and hearing in noise with the Oldenburg sentence test (OLSA) in sound field with the contra-lateral ear plugged and muffled. Subjective benefit was assessed with the APHAB.
Results: Compared to unaided condition there was a significant improvement of aided threshold, word recognition score (WRS) and speech reception threshold (SRT) in noise for both devices. The comparison of both devices revealed a minor but not significant difference in functional gain (Bonebridge: PTA=27.5 dB (mean); BAHA: PTA=26.3 dB (mean)). No significant difference between the two devices was found comparing the improvement in monosyllable WRS and the SRT, measured with the OLSA (Bonebridge: ρWRS=80%, ρSRT=6.5 dB SNR; BAHA: ρWRS=77.5%, BAHA: SRT=6.9 dB SNR (median)).
Conclusion: Our data shows that the transcutaneous bone conduction instrument can be an audiological equivalent alternative to bone anchored devices avoiding the transcutaneous abutment.

Session B3

Topic: Diagnostics

B3-1) Aural acoustic wideband measurements in infants of ambient and tympanometric reflectance and equivalent admittance

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Background: Transient middle-ear problems influence test outcomes of newborn hearing to identify hearing loss in the initial hospital screening and follow-up diagnostic exams. Wideband aural acoustic testing using reflectance and admittance provide functional information on ear-canal and middle-ear status.
Methods: Aural acoustic research tests at half-octave frequencies from 0.25 to 8 kHz included reflectance parameterized by absorbance and group delay, and equivalent admittance transformed to the plane of the eardrum by representing the ear canal as a cylinder with fixed cross-sectional area and length (estimated acoustically). Newborn infants in well-born nursery and neonatal intensive clinic populations were screened into pass and refer groups with a clinical two-stage otoacoustic emission and automated auditory brainstem response (ABR). Infants were tested at age one month using diagnostic toneburst ABR (air and bone), and at ages 6, 9 (with visual reinforcement audiometry VRA exam), and 12 months. A normal group of ears was identified based on a pass in the screening, diagnostic ABR and VRA exams, and a conductive group based on diagnostic ABR at one month.
Results: Ambient reflectance tests in the normal group had a more immature pattern at screening and one-month relative to tests at older ages. Tympanometric reflectance showed evidence of increased ear-canal collapse in younger infants in up-swept relative to down-swept tympanograms. Tympanometric absorbance had a single-peaked shape relative to reduced absorbance at pressure extrema (300 and -200 daPa). Equivalent admittance was interpretable in infants aged six months and older, but not in younger ages due to ear-canal wall mobility. Mean absorbance and group delay varied with age in normal ears, and differed significantly in normal and conductive groups.
Conclusion: Aural acoustic wideband measurements vary across age in infants and can be used to identify ears with conductive loss in newborns and infants. (Research supported by NIH grant DC010202)

B3-2) Creating borderline situations in middle ear surgery: is there a value of virtual tympanotomy?

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PORP and TORP as alloplastic prostheses are commonly used for ossicular replacement in reconstructive middle ear surgery. One main reason for lack of hearing improvement after middle ear surgery could be prosthesis dislocation or incorrect prosthesis coupling. It was the aim of this study to investigate if so-called borderline situations with minimal shifting of the prosthesis could be experimentally evaluated using different imaging techniques like conventional CT, cone-beam CT (cb-CT) or flat-panel CT (fp-CT). We furthermore investigated whether a 3-D view of prosthesis coupling could help to prevent or indicate revision surgery.
PORP or TORP were used in order to reconstruct the middle ear in 6 fresh temporal bones. Initially prosthesis coupling was performed with best functional results under control of Laser-Doppler-Vibrometry (LDV). In addition we performed progressively decoupling of the prosthesis until borderline situations were reached when middle ear transfer function decreased completely. The different positions of the prosthesis during decoupling were evaluated by use of LDV as well as cb-CT. The final prosthesis position was investigated using CT, cb-CT, fp-CT and 3-D reconstruction.
Best results concerning the depiction of anatomical structures, position and coupling of inserted prostheses were achieved by cb-CT. So far all of the used imaging techniques qualified for position control of middle ear prostheses but cb-CT provided excellent resolution and comparably outstanding 3-D-quality while offering the lowest irradiation dose.
In particular cb-CT and fp-CT were best in delineating prosthesis-related causes for unsatisfying hearing improvement. Therefore these two imaging techniques seem to be helpful in sharpening indications for or against revision surgery. However, while all imaging techniques are powerful in evaluating coupling problems concerning bone and metal they fail more or less when it comes to evaluation of soft tissue problems. Unfortunately soft tissue problems in middle ear reconstruction as e.g. cartilage covering of the prosthesis plate may also be part of borderline situations.

B3-3) Effects of static negative middle ear pressure on wideband acoustic immittance

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Introduction: Wideband acoustic immittance (WAI) measurements are capable of evaluating middle ear performance over a wide range of frequencies relevant to speech perception and human hearing. It is known that static negative middle ear pressure (NMEP) affects sound transmission to and from the cochlea, but few data sets exist to quantify this relationship.
Methods & Materials: Eight subjects with normal middle ear function were trained to induce highly consistent NMEPs using the Toynbee maneuver. NMEPs were quantified by the tympanic peak pressure (TPP), and the WAI was measured. The WAI near the tympanic membrane (TM-WAI) is estimated using a published method that accurately removes the residual ear canal contributions to the measurement, thus allowing for a direct comparison of the complex TM-WAI (magnitude and phase) for different subjects and probe insertion depths.
Results: For these subjects, NMEP has the largest and most significant effect (a mean change of 2-3 [dB]) between 0.8-1.8 [kHz], causing less energy to be absorbed by the middle ear and cochlea. The TPP level was found to be a significant, but imperfect predictor of TM-WAI change, which is non-linear as a function of TPP. Changes in the TM-WAI appear consistent with a stiffening of middle ear structures in the presence of NMEP, possibly including the annular ligament.
Conclusions: As the effects of NMEP on the TM-WAI vary widely across subjects, in both magnitude and frequency range, a modeling approach allows us to better quantify these effects. In this case, the use of network modeling techniques to study the stiffness changes in the middle ear is superior to comparing WAI data in frequency bins, due to the frequency dependence of the changes. Thus, it is important to consider the complex (magnitude and phase)TM-WAI which we estimate accurately by removing the effect of the residual ear canal.

Session B4

Topic: Bone Conduction

B4-1) Model predictions of bone conduction hearing in the human

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Background: Several pathways have been suggested for the perception of bone conducted (BC) sound in the human. Five different pathways is often suggested as important: (1) sound pressure in the ear canal, (2) inertia of the middle ear ossicles, (3) inertia of the inner ear fluid, (4) compression of the inner ear space, and (5) pressure transmission from the skull interior. The relative importance of these pathways has been

debated with no consensus.
Methods: An acoustic-impedance model of the middle and inner ear was developed. The model comprises all 5 pathways listed above. Moreover, the model uses experimental data from ear canal sound pressure, middle ear ossicle motion, cochlear promontory motion, and intra-cranial sound pressure during BC stimulation. The excitation of the basilar membrane from each pathway was computed using the model.
Results: The model simulations indicate that the two inner ear pathways, fluid inertia and compression of the inner ear space, were most important for BC hearing. Of these two, fluid inertia was 5 to 15 dB more effective than compression even if compression became important at limited frequency ranges. Of the other pathways, inertia of the middle ear ossicles gave basilar membrane excitation that was 10 to 20 dB below the inner ear contributions while sound pressure in the ear canal was some 10 dB below the inertia of the middle ear. Pressure transmission from the skull interior was close to the inner ear pathways at the lowest frequencies but diminished with frequency and was more than 60 dB below the inner ear pathways at 10 kHz.
Conclusion: A acoustic-impedance model for BC hearing in the human was able to predict the relative importance the different pathways where the inner ear was found most important. The model predictions were in-line with available experimental data.

B4-2) Bone conduction: what contributes to Carhart's notch?

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Introduction: Carhart's notch – an increase in bone conduction (BC) threshold at around 2 kHz in patients with stapes fixation – has been attributed to the loss of the middle-ear inertia's contribution to BC hearing at the resonant frequency of the middle ear (1-2 kHz). Recently, computational models have described other BC mechanisms that may be important to Carhart's notch. The goal of this study is to determine experimentally the cause of Carhart's notch.
Methods: Intracochlear pressures in scala vestibuli and scala tympani of 8 cadaveric temporal bones were measured with micro-fiberoptic sensors sealed within the inner ear. Stapes and round-window velocity magnitudes and phases were checked for stability before and after sensors were inserted, and phase between stapes and round-window motion were verified to be opposite. The sensors were rigidly secured to the otic capsule with cement to prevent relative motion between the sensors and bone. The difference in scalae pressure, the pressure drive to cochlear partition motion, was measured during BC stimulation with a bone-anchored hearing aid under three experimental conditions: 1) normal intact ossicular chain, 2) ossicular discontinuity at the incudo-stapedial joint to remove a majority of the middle-ear inertia, and 3) fixation of the stapes footplate.
Results: Ossicular discontinuity decreased the pressure drive by ~10 dB around 0.8-2.3 kHz. Stapes fixation produced an additional ~10 dB decrease in a wider frequency range around 0.7-4 kHz in 6 of 8 ears, suggesting that the reduction in oval-window mobility contributes to the total loss.
Conclusion: Our data suggests that Carhart's notch, often seen in stapes fixation, depends on both the reduction of middle-ear inertial drive and the reduction in oval-window mobility.
This work was funded by NIH/NIDCD R01DC013303

B4-3) Bonebridge® implant in adults and children: computer assisted 3D planning and audiological outcome

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Background: The study aimed on evaluating the benefit of a preoperative three-dimensional (3D) planning tool for surgically placement the bone conduction floating mass transducer (BC-FMT) of the Bonebridge (BB) bone conduction implant (BCI).
Methods: A preoperative planning tool was developed, allowing to freely adjust the Bonebridge implant in an individual 3D model of the skull for checking the possibility of completely fitting the BC-FMT into a bony bed and finding an optimal implant position. In the period from 2012 to 2015 the Bonebridge was implanted with mastoid or retrosigmoid placement after individual preoperative planning and "virtual surgery" in 11 adult and 6 pediatric patients (Age: mean = 34 y +/- 22,18 SD; min 5, max 76 y) with conductive or mixed hearing loss due to chronic ear disease, malformation, or single sided deafness. The main outcome measures were feasibility of the preoperative 3D planning process, transfer into the intraoperative situation and audiological results after implantation.
Results: Individual preoperative planning was considered beneficial especially in cases of small mastoid bone volume,

e.g. in children or cases malformation (including a case with simultaneous implantation of bone anchors for an ear prosthesis), and due to previous canal wall down mastoidectomies. Audiological data showed a significant benefit 3 months after implantation. These results were comparable to those reported in the few case series on Bonebridge implantation published so far and to those from studies with the Baha implant.
Conclusion: For optimal placement of the BC-FMT of the BB, preoperative 3D planning is recommended especially in primarily small, poorly pneumatized mastoids, hypoplastic mastoids in malformations, reduced bone volume after canal wall down mastoidectomy, small mastoids in children, and for planning of simultaneous implantation of bone anchors for ear prostheses. Efforts should be made towards reducing segmentation and surgical planning time by means of automatization.

B4-4) BAHA Attract – first Nordic results on a new transcutaneous bone conduction hearing solution

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Background: As part of a pre-market release a brand new transcutaneous bone anchored hearing aid was implanted. As this transcutaneous solution differs from other similar devices, and because sound transmission may be compromised compared to standard percutaneous devices, this study focuses on the audiological results with this new device.
Method: Prospective multi-center study with a case-series of 23 consecutive patients with both objective and subjective outcomes of the new transcutaneous bone conduction hearing solution BAHA Attract. At a half-year follow-up, aided and unaided sound field hearing was evaluated by 1) pure warble tone thresholds, 2) pure tone average (PTA), 3) speech discrimination score (SDS) in quiet and 4) speech reception threshold 50% at 70 dB SPL noise level (SRT50%). Subjective benefit was evaluated by four questionnaires: 1) the IOI-HA, 2) the SSQ12, 3) the GHABP and 4) a questionnaire questioning frequency and duration of device use.
Results: Study is still ongoing and the results will be presented at the MEMRO 2015 congress
conclusion: A conclusion will also be presented but is at the moment not possible because the final data analysis is still taking place. The results are due end of April 2015.

B4-5) Application of bone conduction implants Med-El Bonebridge in adult patients with congenital or acquired hearing loss – first experience

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Backgrounds: Med -El Bonebridge is a new active bone conductive implant. Bonebridge device may be used in adult patients suffering from hearing loss of different origins – acquired and congenital. The device provides conduction of sounds directly to the inner ear, bypassing middle ear structures either underdeveloped or damaged with an inflammatory process. The aim of the study is presentation of the first experience with the device and discussion of applied surgical technique in patients after radical modified mastoidectomy operations.
Methods: Material consists of 21 patients operated in 2012-2014. A bone conduction transducer of Bonebridge device was placed in a special bony bed under skin and fixed with two short osseointegration screws. In cases after modified radical mastoidectomies posterior wall of the external auditory meatus was reconstructed. The surgeries lasted for about an hour. During the surgeries as well as the postoperation period no complications were noticed. It is worth to mention that due to the dimensions of the bone transducer (8,3 mm) it is necessary to assess preoperatively the possibility of implant application using computer tomography analysis.
Results and conclusions: the first experiences with the device are very encouraging. Authors state that the Bonebridge device is very promising as it provides significant amplification which results in better speech discrimination. The device does not have any percutaneous elements therefore it does not cause any inflammatory conditions of the surrounding tissues.

B4-6) Intracranial sound pressure during BC stimulation

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Background: Bone conduction (BC) pathways are believed to involve vibration of the skull bone. Recent studies proposed direct stimulation of the inner ear fluid via non-osseous pathways such as soft-tissues, the brain, and cerebro-spinal fluid. Contribution of these pathways to hearing and their interaction with osseous pathways are still unresolved. This study investigates the role of intracranial pressure during BC stimulation.
Methods: Simultaneous measurements of intracranial pressure by a hydrophone (positioned in the central and in the temporal region) and promontory motion by a Laser Doppler Vibrometer were made in Thiel-embalmed human cadaveric heads. Stepped harmonic excitation, in the range of 0.2 – 10 kHz, was applied via a BC hearing aid (BCHA), attached by an implanted screw, a soft-band, or 5-Newton steel-band. The BCHA was consecutively attached at six different locations: ipsilateral and contralateral mastoid, via screw and steel-band; forehead, eye and neck, via steel-band; dura, after craniotomy, via soft-band. Promontory motion and intracranial pressure were compared.
Results: While the ratios of the intracranial pressure at the center of the intracranial space to the cochlear promontory motion were similar for stimulation on the mastoid, forehead, eye, and neck, the ratio for stimulation on the dura was higher than the ratios for stimulation on the other sites. For stimulation of the BCHA at the ipsilateral and contralateral mastoid, the phase of the intracranial pressure (measured in the temporal region) and promontory motion reveals similar transcranial delays, and transcranial magnitude attenuation was observed only for the intracranial pressure.
Conclusion: Intracranial pressure and promontory vibration are measureable for stimulation on the mastoid, forehead, eye, neck, and dura. The intracranial contents and promontory motion are presumed to interact and not to be independent for stimulation on mastoid, forehead, eye, and neck. The dura stimulation causes excitation mainly on the intracranial contents.

Session C1

Topic: Evolution, Development, and Imaging

C1-1) Changes in dynamic characteristics of the external ear canal wall during the first 3 months of life

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Introduction: A sweep frequency impedance (SFI) meter, which evaluates the dynamic behavior of the middle ear, allows the diagnosis of middle ear dysfunctions in adults and children. Recently, SFI tests were performed in neonates. The results showed two variations in the sound pressure level (SPL) at around 0.3 and 1.0 kHz, the former and latter being possibly related to the resonance of the external ear canal wall and that of the middle ear, respectively. However, it is unclear how long the external ear canal wall has an influence on the SFI data. To establish reliable diagnostic criteria, elucidation of the chronological changes in dynamic behavior of the neonatal hearing system is indispensable.
Materials and methods: SFI tests were performed in a healthy neonate, who was a full-term baby with normal perinatal history and who passed the automated auditory brainstem response test, at 6, 14, 23, 38 and 92 days after birth. This study was approved by the Ethics Committees on Clinical Investigation of Tohoku University School of Medicine and the Japanese Red Cross Sendai Hospital.
Results: At 92 days after birth, the frequency RF1, at which the first variation in the SPL curve was observed, increased by 1.59 times and the changes in the SPL (ΔSPL1) decreased by 0.39 times as compared with those at 6 days after birth. On the other hand, changes in the RF2 and the ΔSPL2 were not that much. These results suggest that the rigidity of the external ear canal wall increases with an increase in chronological age, resulting in an increase and decrease in the RF1 and ΔSPL1, respectively.
Conclusions: The measurement data implied that the dynamic characteristics of the external ear canal wall changes with growth, possibly due to the increase in the rigidity of such wall.

C1-2) Evolution of modern human middle ear ossicles – Evidence from extant and extinct species.

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Studying middle ear ossicles improves our understanding of human evolution in thus far unexplored ways. Identifying what is uniquely human about our ossicles is also valuable for answering clinical problems. The evolution of human ossicles can be deduced from the hominin fossil record and from comparison to our closest living relatives, the great apes. However, the ossicles only occasionally survive as fossils and comparisons between species have been marred by analytical problems related to their diminutive size and complex shapes. Hence, a thorough picture of how the modern human ossicles evolved does not exist to date.
Here, we present a study of the 3D shape of ossicles as found among modern humans, great apes and extinct human ancestors, ranging from australopiths to Neandertals. The analyses use a geometric morphometric (GM) measurement protocol based on 3D landmarks obtained from high resolution CT images. Landmarks were analyzed using principal component analysis after standardizing for position, orientation, and scale. Moreover, the relationship between the ossicles and the surrounding tympanic cavity was assessed quantitatively, and 3D visualization of extant soft-tissue specimens provides the basis for inferring the spatial arrangement of the ossicles in fossils.
The results of the GM analyses show that the ossicles of all species can be distinguished by their shape (statistical significance $P<0.01$). Modern humans show a mosaic of derived and primitive characteristics, and differ widely from their ancestors in spatial arrangement of the ossicles.
Our analyses add to the understanding of the nature, pattern and underlying causes of morphological change shown by the ossicles during human evolution. The results provide the basis for investigating the auditory capacities of our ancestors.

C1-3) Signalling of different Wnt pathway members accompany the developmental processes of middle ear formation

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Introduction: Development of a tympanic middle ear of vertebrates involves the formation of a layered tympanic membrane, 1-3 ossicles, and the muscles and blood vessels associated with them. These structures, and the middle ear cavity itself, arise through the orchestration of tissues from diverse embryological origins, including the surface ectoderm, mesenchymal cells of both neural crest and mesodermal lineages, and the pharyngeal endoderm. The search for secreted signalling families that mediate the coordination of these morphogenetic events is ongoing. Genes of the different Wnt pathways are deeply involved in development and disease of vertebrates and are therefore prime candidates.
Methods: In situ hybridization of tissue sections through embryonic chicken heads was conducted to evaluate how spatiotemporal maps of Wnt-related gene expression overlap with middle ear development.
Results: Wnt11 labels migrating neural crest cells and is later transcribed at the tympanic membrane. In the tympanic mesenchyme, transcripts for Wnt11 superimpose with those of Fz1 and Fz7 receptors and the Wnt antagonist Dkk1. During middle ear cavitation Fz1 is present in the mesenchyme that finally becomes cleared off to give room for the surrounding otic cartilage which in turn transcribes Fz9. Early, the Wnt antagonist SFRP2 is prominently expressed in the condensing mesenchyme of the forming middle ear ossicle, the columella, prior to chondrogenesis. Later, SFRP2 disappears from the columella and columellar chondrocytes express another Wnt antagonist Frzb1, and also Fz9. In a complementary pattern to Frzb1, SFRP2 labels the columella perichondrium; it is also present in the surrounding mesenchyme.
Conclusion: These gene expression patterns suggest a multistep involvement of the Wnt pathways during middle ear formation. Knowledge of such complex spatial and temporal control of gene activity could offer an avenue to understanding the causes of congenital anomalies leading to conductive hearing loss.

C1-4) High frequency ultrasound and optical coherence tomography: New technologies for non-invasive high resolution middle ear imaging and vibrometry

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Visual inspection of the middle ear is an important step in the diagnosis and monitoring of many ear pathologies. Direct examination via a myringotomy can be performed but less invasive methods are much preferred. However, commonly used non-invasive techniques for imaging the middle ear, such as computed tomography and magnetic resonance imaging, often do not provide clinicians with sufficient image resolution, as well as having other important drawbacks. Two imaging technologies “high frequency ultrasound (HFUS) and optical coherence tomography (OCT)“ are here described along with investigations into their ability to image and measure vibra-

tions of the middle ear with minimal invasiveness.
Unfixed human cadaver temporal bones were imaged and vibrometry performed with HFUS and OCT with a normal middle ear anatomy, as well as following manipulations to simulate some clinical conditions of interest, including an eroded long process of the incus, and various ossicular replacement prosthesis configurations. A commercially available HFUS system or an in-house built miniaturized endoscopic HFUS system was used, and OCT was performed using an in-house built system being designed for integration with traditional surgical microscopes.
HFUS using both the commercial and endoscope systems yielded images with readily identifiable middle ear structures. Vibrometry of ossicles in response to acoustic stimulation was successful using HFUS and OCT, although responses were considerably damped with HFUS due to the necessary loading of the TM surface and middle ear space with fluid medium.
We conclude that both HFUS and OCT are promising new approaches for high resolution real-time imaging of the middle ear that can likely provide clinicians with valuable data which was previously unattainable through non-invasive means. Furthermore, both techniques are relatively simple to use and safe, and the equipment could easily be used directly in the otology clinic.

Session C2

Topic: ME Physiology and Pressure Regulation

C2-1) Ossicular chain motion during low frequency and high intensity sound stimulation

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Introduction: High intensity sounds can cause profound sensorineural hearing loss. Measurements of ossicular motion have proven to be useful for the exploration of normal and pathological processes of ossicular transmission; however, previous studies have either relied upon measurements in animal models or measurements at lower sound intensities. Here, we report results from scanning LDV measurements on the ossicular chain in human cadaveric temporal bones, during presentation of harmonic and impulsive stimuli in the ear canal at intensities exceeding 170dB peak SPL.
Methods: Hemicephalic human heads were prepared by mastoidectomy and extended facial recess approach to expose the ossicular chain. Harmonic (20 Hz - 2.5kHz) and impulsive (simulated blast) stimuli, were presented using a custom designed closed-field, high-intensity acoustic system. Scanning laser Doppler vibrometry (sLDV) measurements on several points on each component of the ossicular chain were made simultaneously with recordings of the SPL in the ear canal during high intensity sound stimulation (115-165 dB SPL). Responses were analyzed in both the time and frequency domains.
Results: Rigid body motion of the ossicular components was approximated from out-of-plane motion recorded by the sLDV system. Displacement and axis of rotation were found for the incus, and complex motion of the stapes assessed, over a range of frequencies and intensities. Results show changes in the modes of ossicular motion at the highest frequencies tested consistent with prior results at lower intensities. Nonlinearities were also observed at the highest intensities tested, suggesting visco-hyperelastic behavior of the annular and suspensory ligaments.
Conclusions: These results are useful for characterizing the transmission of low frequency and high intensity sounds through the middle ear, suggest improvements to methods of auditory hazard prediction and provide reference data over a lesser-known regime of frequencies and sound pressures useful to future mathematical models of the human middle-ear.
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C2-2) Congestion of mastoid mucosa and influence on middle ear pressure

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Introduction: Micro-CT scanning of temporal bones has revealed numerous micro-channels, which connect the outer bone surface directly to the underlying mastoid air cell system. Their structure and dimensions suggested a separate vascular supply for the mucosa, which may be involved in middle ear pressure (MEP) regulation. The purpose of our study was to investigate this hypothesis by studying the reaction of the mastoid mucosa in response to adrenergic stimulation administered at the surface of the micro-channels – a resulting decongestion of the mucosa should be reflected by a reduction in MEP.
Methods and Materials: 20 healthy adults were included. Initially tympanometric determination of the MEP was done in the sitting position, after which the supine position was taken; then the ear was injected retro-auricularly with a 1 ml isotonic NaCl solution, and subsequently, the MEP was monitored by serial tympanometry over five minutes. This exper-

iment was repeated with an injection of 1 ml epinephrine solution retroauricularly (5 mikrogram/ml).
Results: In control ears (NaCl) the MEP showed an immediate increase in response to changing body position; this pressure increase remained stable for the entire period up to 5 min. In test ears (epinephrine) MEP also showed an initial increase, but it was followed by a distinct pressure decrease, which subsequently increased towards the same levels as the control ears at 5 min.
Conclusions: Administration of retroauricular subcutaneous epinephrine caused a distinct decrease in MEP compared to control ears. This can be explained by the micro-channels were able to convey the epinephrine to the underlying mastoid and its mucosa; this caused a vascular constriction and decongestion of the mastoid mucosa, which ultimately resulted in a MEP decrease (Boyle's Law). Thus, our results demonstrated that the mastoid mucosa seem to be susceptible to vaso-active mediators, which may play an important role in MEP regulation.

C2-3) Tympanic membrane pressure buffering in the quasi-static pressure regime

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Background: Human ears are subject to high pressures fluctuations in the quasi-static pressure regime that have amplitudes of tens of KPa. These pressure changes happen in our daily life, and they are generally known to have an influence on hearing thresholds. However, the way of which the tympanic membrane (TM) acts to regulate such quasi-static high pressure is still seems debatable.
Method: A setup was developed to measure pressure in the middle ear (ME) as a function of sinusoidal pressure variations applied to the ear canal (EC). The technique was used in-vitro in rabbit ears, with frequencies ranging from 0.5 Hz to 50 Hz and peak-to-peak amplitudes from 0.5 kPa to 2 kPa.
Results: The trans-tympanic pressure difference was found to be the smallest in the quasi-static range, and quickly increasing as a function of frequency. The response curves show asymmetry, with larger trans-tympanic pressures for positive pressure values in the EC. Normalized trans-tympanic pressure amplitudes remain fairly constant, with values in the range of 60% to 70% relative to the applied pressure. Total harmonic distortion (THD) was calculated from the ME pressure signal with respect to the EC pressure signal and found to be < 2% for low-pressure amplitudes and low frequencies. When pressure is increased to 1 kPa, THD increases to about 10% at 50 Hz. However, THD of 30% were observed when pressure reaches amplitude of 2 KPa at 50 Hz.
Conclusion: It was found that the trans-tympanic pressure load is the lowest in the quasi-static range, and quickly increases as a function of frequency. When sinusoidal varying EC pressure is applied, THD is very small for low frequencies and pressure amplitudes, meaning that the overall TM motion follows the applied pressure well.

C2-4) Determination of the mastoid surface area and volume based on micro-CT-scanning of human temporal bones. Geometrical parameters dependence on scanning resolutions.

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Background: The mastoid air cell system (MACS) consists of a larger complex of interconnected air cells. Opposed to a single large cavity, this structure reflects a large surface area (SA) to volume (V) ratio (SA/V), which may indicate that the MACS is adapted to gas exchange and has a potential role in middle ear pressure regulation.
Thus, the MACS has been studied by high resolution clinical CT scannings determining the SA and V. However, the resolution of these is limited to around 0.6 mm, and so is also the estimation of geometrical parameters. Air cells may appear below the resolution and cannot be detected. Such air cells may contribute to a much higher SA than estimation of the V, and thus, also the SA/V. These parameters are important for the function of the MACS including physiological modeling. Our aim was to determine the SA, V, and SA/V in the human MACS at highest resolution by using micro-CT-scanning on temporal bones. Further, the influence of the resolution on these parameters was investigated by downsampling the data.
Materials & Methods: Eight normally aerated temporal bones were scanned at highest possible resolution (30-60 micrometers). The SA was determined by a triangular isosurface mesh fitted to the MASC, whereas the V was determined by summation of air containing voxels. Downsampling of the original data was done four times by a factor of 2.

Results: The mean SA was 194 cm2, the mean V was 9 cm3, and the mean SA/V amounted to 22 cm-1. Decreasing the resolution resulted in a non-linear decrement of SA and SA/V, whereas V was constant.
Conclusion: The current study found significantly higher SA and SA/V than previous studies at lower resolutions. These findings are important for a more accurate modeling of the middle ear physiology.

Session C3

Topic: Surgical Techniques and Reconstruction

C3-1) Intraoperative online monitoring of ossiculoplasty using LDV – first clinical measurements

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Background: Hearing results after tympanoplasty with ossiculoplasty depend on several biological and biomechanical factors. One important factor is the "fine tuning" of the prosthesis by the surgeon. The placement and adaption of the prosthesis can influence the hearing outcome up to 15 dB in some frequencies. Until now the surgeon's experience is the only parameter that influences the tuning process since no intraoperative equipment is available.
Methods: A new measurement set up, consisting of an electromagnetic stimulation system and a Laser Doppler Vibrometer (LDV) to measure stapes vibration, has been developed to measure middle ear transfer functions (METF) during surgery. The coil of the electromagnetic stimulation system is placed below the head of the patient. A sterilized magnet is placed at the umbo. This way, manipulation at the ossicular chain is possible with real time control of stapes vibration by LDV. The LDV system was mounted to the microscope and the surgeon receives the signal feedback by headphone.
Results: We investigated 13 patients with cochlear implant surgery and 10 patients with tympanoplasty. In 17 cases an LDV signal from the footplate was successful obtained in the frequency range of 200-4000Hz. The measurements from the cochlear implant patients serve as reference data for intact middle ears. These reference METF show the same variation as known from normal METF with sound stimulation. We demonstrate also the use of the measurement set up in 4 cases of tympanoplasty. In 2 cases the footplate vibration could be improved after using the online measurement system by about 10 dB.
Conclusion: The new developed measurement system is easy to handle during surgery and it is suitable to improve the hearing results after tympanoplasty. More patients have to be included into the study to verify the effect of different reconstruction methods and different prosthesis design.

C3-2) Intra-operative assessment of ossicular fixation

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Background: A variety of conditions such as otosclerosis and malformations, and sequels of chronic otitis media such as tympanosclerosis and adhesions can cause more or less fixation of the middle ear ossicles, which leads to hearing impairment. In order to intra-operatively determine the best course of surgical treatment, knowledge of the degree of ossicular mobility is useful. Ossicular assessment is routinely performed by manual palpation during surgical exploration, but this is subjective and imprecise. Furthermore, manual pressing tests the quasi-static mechanical properties, which don't necessarily coincide with the middle ear's acoustic properties. A more objective method to assess mobility will be useful.

Laser-Doppler vibrometry allows non-contact measurements on the nanometre scale, and is the standard tool to measure ossicular motion in experimental situations. However, during exploratory tympanotomy the middle ear cannot be driven by acoustic stimulation. Therefore if laser vibrometry is to be used as a tool to assess ossicular fixation, an alternative means of driving the ossicles is needed.
Method: We developed a novel non-contact method that makes use of a small magnet and coil to vibrate the ossicles. The method allows the ossicles to be driven at acoustic frequencies yet allows free visual access for a laser vibrometer. We evaluated the method on temporal bones with various degrees of ossicular fixation, and with fixations at various locations in the ossicular chain.
Results/conclusion: The method appears easy to implement in a clinical setting. The vibrometer can be combined with a surgical microscope and both the coil and reflective tape can easily be sterilised. Information on the degree of ossicular fixation can be found by measuring the velocity ratio between different points along the ossicular chain. In an unfixed state the velocity ratios appeared to be within a well-defined range, and increasing fixation caused the ratios to fall progressively further outwith this range.

C3-3) A new flexible TORP with silicone coated ball joint and its properties

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Background: Tilting and dislocation of middle ear prostheses are some of the known complications after middle ear surgery. They are related to loads at the implant coupling points, in response to a tension change in the middle ear. The healing process, scar tension, and static pressure variations are possible causes. A new total ossicular replacement prosthesis (TORP) prototype with a ball joint and silicone coating has been developed. The main feature is to reproduce the viscoelastic behaviour of the ossicular chain.
Methods: The middle ear transfer function (METF) in temporal bones, using flexible TORPs, was measured. Also, the influence of static pressure changes of about 2.5 kPa was therefore determined. The experimental data was compared to the sound transfer function of the intact ossicular chain and the middle ear reconstruction with rigid TORPs. The mechanical properties of the prostheses were investigated with force measurements.
Results: At normal pressure the METFs of the rigid and the flexible TORPs are comparable on average. Because of the bigger tension between the tympanic membrane and the annular ligament, slightly more losses below 1 kHz occur in the transfer function using the rigid prostheses. Ambient pressure causes bigger transfer losses at lower frequencies with the rigid TORP reconstruction. The new TORP design is able to prevent the inner ear of being damaged, e.g. at ambient pressure changes.
Conclusion: Compared to rigid TORPs, the transfer behavior at ambient pressure can be improved using the coated micromechanical joint design instead. It also prevents dislocation. The new construction is a good attempt for improving standard passive prostheses, from their rigid design to a flexible one.

C3-4) Round window vibration induced by new chamber stapes prosthesis: preliminary results of experimental investigation.

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Background: The most common method for otosclerosis treatment is stapedotomy surgery with piston stapes prosthesis. The piston-stapedotomy gives good hearing outcomes but only for low and medium frequencies (0.5–3kHz). Recently, we have proposed new design of chamber stapes prosthesis (ChSP). To date, this prosthesis was only numerically simulated. The aim of this study was to experimentally implant a first ChSP prototype and to measure the round window (RW) vibration before and after implantation.
Methods: The measurements were performed on human cadaver temporal bone. The acoustic signal (90dB SPL, 0.8-8 kHz) was introduced to an auditory canal by a loudspeaker (ER-2 Etymotic Research). The 90-dB SPL was controlled by a microphone (ER-7C) positioned near the tympanic membrane. The RW vibrations before and after the ChSP implantation were recorded using a scanning laser Doppler vibrometer (PSV400, Polytec). Additionally, after implantation, vibrations of the prosthesis plate were measured to compare them with the stapes vibrations in the normal ear.
Results: For medium and high frequencies (1.5-8 kHz), the RW vibration induced by the new prosthesis was 10-20 dB higher in comparison to the normal ear. In the post-stapedotomy ear, the RW vibrations were approximately 2-fold higher than vibrations measured on the prosthesis' plate. For all measurement frequencies, the plate vibrations were piston-like with the amplitude close to the stapes amplitude. In comparison with a 0.4-mm piston prosthesis, the ChSP induces the RW vibration higher by 3-6 dB and 10-30 dB for frequencies of 0.8-1.25 kHz and 1.5-8 kHz respectively.
Conclusion: New ChSP efficiently transmits sound vibrations into the inner ear. The preliminary results suggest that the ChSP may provide better hearing results than the piston prosthesis, especially for frequencies above 3 kHz. Further studies are necessary to optimize geometry and to develop appropriate technology for the new prosthesis.

C3-5) Influence of prosthesis' length on middle ear transfer function

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Background: Applying the correct prosthesis' length in ossiculoplasty is crucial for the postoperative hearing outcome. Short prostheses run a higher risk of dislocation whereas too long prostheses create tension on the (reconstructed) tympanic membrane (TM) and the annular ligament (AL) decreasing the middle ear transfer function (METF). The aim of this study was to investigate both, the impact of a prosthesis elongation inserted between the malleus handle and the stapes footplate and the isolated effect of an AL stiffening on the METF.
Methods: To measure the influence of prosthesis' tension on the METF an experimental titanium nitinol prosthesis was interposed between the malleus handle and the stapes footplate. Heat-activation induced a prosthesis shaft elongation. During sound excitation via the external ear canal the effect on the METF was monitored online by LDV on the footplate. Thereafter, the TM and AL stiffness were measured in each specimen. To further elucidate the impact of the AL alone, a FMT for sound excitation was coupled on the stapes head and successively pushed towards the vestibulum. The effect of the AL stiffening on METF was determined by LDV on the footplate.
Results: TORP elongation was partly borne by TM and AL. A mean elongation of 150 µm created a METF reduction of 15 dB, with a greater effect in the lower frequencies. TM stiffness remained constant, whereas AL stiffness increased up to the factor 8. The isolated AL proportion accounted for up to 25dB when the footplate was shifted 70 µm towards the vestibulum, leading to a 15-fold stiffening.
Conclusion: Prosthesis' length has an enormous effect on METF by stiffening of the AL. Therefore, as little tension as possible should be applied in ossiculoplasty.

C3-6) Titanium PORP's and TORP's versus autologous ossicles. Clinical results in 337 tympanoplasties

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Background: Reconstruction of the middle ear ossicles is frequently needed in otosurgery in order to preserve or restore hearing. Autologous ossicles are well suited for this, but in cases with erosion artificial prostheses must be used. Titanium PORP or TORP's have been quite popular, since they represent high biocompatibility and good acoustic properties including low weight and high stiffness. However, their long-term results still remain to be documented.
Purpose: The purpose of the present study was to evaluate our experiences with titanium PORP and TORP's compared with autologous ossicles in middle ear reconstructions. This included the the hearing results and clinical course with an emphasis on extrusion with minimum 1-year follow-up.
Material and Methods: During the study period from 2008 to 2010 337 ossiculoplasties were identified in our database (101 titanium prostheses and 236 autologous ossicles). Patient records were reviewed in order to identify ossicular reconstructions (type II and III with intact stapes and destructed supra-structure, respectively; and PORP's and TORP's). In addition, the audiometric results (PTA4) were registered as well as the status of the tympanic membrane.
Results: We identified 68 PORP and 38 TORP's among 101 titanium reconstructions; further, 183 type II and 53 type III among 236 autologous reconstructions. The audiometric results will be presented graphically at the meeting. The mean follow-up time was 2.4 year, and we found 12 cases of prosthesis extrusions.
Conclusions: The audiometric results for PORP and type II reconstructions were not significantly different; however, the TORP reconstructions were significantly better than type III reconstructions. Extrusion of the titanium prostheses was limited to 4 % of the cases. Prospective randomized studies are warranted.

C3-7) Theoretical and practical considerations of 3-dimensionally printed biomimetic tympanic membrane grafts: preliminary design, manufacture, and acoustic testing

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Background: Patients with chronic otitis media and Eustachian tube dysfunction (ETD) undergoing tympanoplasty are at risk for re-retraction or perforation of their grafts. Temporalis fascia grafts are often susceptible to changes in shape and structure due to the ongoing ETD. Three-dimensional (3D) printing technology can potentially correct the mechanical limitations of current graft materials, while preserving the acoustic properties. We hypothesize 1) a high-resolution biomimetic tympanic membrane (TM) can be produced using 3D printers and 2) the acoustic properties of a printed TM can be tuned to approximate the properties of the original TM.
Methods: Electron microscopy of the human TM fibrous layer

was used as the basis for TM design. Biocompatible absorbable and non-absorbable materials were printed as either thin uniform sheets or custom-designed TM scaffolds. Scaffolds were then layered with fibrin/collagen infill to create an intact membrane. Acoustic properties of printed TMs were determined by digital opto-electronic holography and compared to fresh human cadaveric temporalis fascia and TMs with intact ossicular chains.
Results: Thin sheets and TM scaffolds of varying diameters, thicknesses, and fiber arrangements were successfully printed. Both thin sheets and scaffold + infill showed frequency dependent variations in motion patterns (number and location of peaks) at 1000, 4000, and 8000 Hz. The motion patterns were affected by sheet material and scaffold design. Several sheet and scaffold + infill designs demonstrated similar patterns to human TM and fascia. The normalized displacement (micrometers / Pa) of several sheets and infilled scaffolds were similar to displacement observed in human temporalis fascia and TMs.
Conclusions: Preliminary studies suggest that 3D printers can produce biomimetic TM grafts with acoustic properties that approximate the TM. These data have implications for the clinical application of 3D printed biomimetic TMs and in understanding the biomechanical properties of the human TM.

Poster presentations

Session P1

Topic: ME Active Implants

P1-1) Audiological evaluation of bone-anchored hearing device using giant-magnetostrictive material

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Background: Bone anchored hearing device, such as BAHA and Bonebridge, is a surgically implantable hearing system in which sound signal is transmitted to the inner ear directly via bone conduction. At present, functional gains of such devices are limited and applied only in patients with bone-conduction hearing loss within 45-50 dB HL. To widen the indication of the device, bone-conduction vibrator needs to be more powerful.
Giant-magnetostrictive material (GMM) is an alloy compound composed of terbium, dysprosium and iron, and has features such as higher power and durability with rapid response. The purpose of this study is to investigate audiological features of GMM as a bone-conduction vibrator in comparison with that of BAHA.
Methods: Subjects were 3 implantees of BAHA. GMM was screwed to the mounting bracket that was fixed on the abutment of BAHA. Test sounds were provided by a speaker placed in front of the patients. Test batteries were pure-tone audiometry and speech discrimination test in quiet and noise circumstances (10-15 dB, white noise). The results were compared between GMM and BAHA.
Results: Frequency response of GMM was almost identical to that of BAHA except at higher and lower frequencies. At 4 kHz, bone-conduction hearing by GMM was better than that by BAHA, while at 0.5 and 0.25 kHz, it was lower than that by BAHA. Speech discrimination scores by GMM were almost identical to those by BAHA in both quiet and noise circumstances.
Conclusion: Present study showed that GMM has similar audiological functions to that of BAHA, although responses at lower frequencies were a little weak. We believe that GMM can be used as a powerful bone conduction stimulator of bone-anchored hearing device, especially at higher frequencies.

P1-2) Audiological results of Codacs™ and cochlear implants: a retrospective comparison

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Background: The new implantable hearing system Codacs™ was designed to close the treatment gap between active middle ear implants and cochlear implants in cases of severe-to-profound mixed hearing loss. The Codacs™ actuator is attached to conventional stapes prosthesis during the implantation and thereby provides acoustical stimulation through a stapedotomy of the oval window to the cochlea. The cochlear implants (CI) are an established treatment option for profound deaf patients. Steady technical improvements increased the speech intelligibility outcome after cochlear implantation. Particularly, the electro-acoustical stimulation moved the indication criteria for cochlear implantation towards the patients with significant residual hearing.
Methods: In this retrospective study, we compared the clinical outcome of 25 patients with the Codacs™ implant to 54 CI patients with comparable pre-operative bone conduction (BC) thresholds that were potential candidates for both categories of devices.
Audiological testing was performed three month (Codacs™ patients) and two years (CI patients) post-activation. Word recognition scores (WRS) were determined using the Freiburg monosyllables in quiet and WRS in noise with the HSM sentences test (+10 dB SNR).
Results: The Freiburg monosyllable WRS in quiet was significantly ($p = 0.03$) better in the Codacs™ than in the corresponding CI patients for pre-operative BC PTA < 60 dB HL and equal in patients with a pre-operative BC PTA between 60 and 70 dB HL.
Speech in noise intelligibility was significantly ($p < 0.001$) better in Codacs™ (80 % median) than in CI patients (25 % median).
Conclusion: Our results indicate for patients with sufficient cochlear reserve that speech intelligibility with the Codacs™ hearing implant is significantly better than with a CI. Further, results in Codacs™ were better predictable, encouraging the extension of the indication to patients with less cochlear reserve than reported here.

P1-3) Comparison of three middle ear sites for the floating mass transducer

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Objective: In the Vibrant Soundbridge System (Vibrant Med-El), the floating mass transducer (FMT) may be placed on the round window (RW), head of the stapes, or the stapes footplate in patients without an intact ossicular chain. Specialized couplers are available for each site. The purpose of this study is to evaluate and compare the acoustic performance of the FMT with appropriate coupler at the three sites in a fresh human temporal bone model.
Methods: Testing of the FMT on the RW with RW coupler was performed in 6 temporal bones; testing of the FMT with a bell attachment placed on the stapes head was performed in 4 temporal bones; testing of the FMT with an oval window (OW) coupler was performed in 6 temporal bones. The method has been described previously (Shimizu et al. 2011) and requires a small opening in the promontory to expose the endosteum. Cochlear fluid displacement was measured at five key auditory frequencies through the opening using a laser Doppler vibrometer and relating this to an equivalent sound pressure level (SPL) at the tympanic membrane (TM).
Results: The RW location produced a cochlear fluid displacement equivalent to a 91.5-119.1 dB SPL input at the TM at the test frequencies. The stapes head FMT location produced a mean response of 94.6-129.8 dB at the same frequencies while the FMT on the footplate produced a mean response of 104.6-134 dB. The OW location produced statistically significant better performance than the RW location at 1.0 and 2.0 kHz.
Conclusion: In this temporal bone model testing system, there was a tendency for the location of the FMT at the footplate and stapes head to provide better transmission at 0.5 to 8.0 kHz than the RW site. However, statistical significance was seen only at 1.0 and 2.0 kHz between the OW and RW sites.

P1-4) Direct stimulation of the round window membrane by Vibrant Soundbridge

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Background: Restoration of hearing using to direct stimulation of the round window membrane is an alternative for the patients with hearing impairment occurring due to the chronic otitis media or lack of the ossicles, also after modified radical mastoidectomy operations. The objective of the study was to analyze hearing results obtained after surgical application of Vibrant Soundbridge in treatment of hearing impaired patients with chronic inflammation of the middle ear, especially after radical modified operations.
Methods: The study included a group of adult patients with chronic inflammation of the middle ear, after radical modified operations with destructed structures of the middle ear - tympanic membrane or/and ossicles. Patients presented conductive or mixed type of hearing impairment. In these patients Vibrant Soundbridge was used as the method of hearing improvement. Surgical approach included Floating Mass Transducer placement in the direct proximity of the round window without using the fascia. We discuss the indications, contraindications and limitations of use of Vibrant Soundbridge in this group of patients.
Results and conclusions: Direct stimulation of the round window is an alternative method of treatment in selected group of patients with hearing impairment and mild to severe destruction of the middle ear elements. In all cases subjective hearing improvement was noticed and confirmed by audiological tests. The hearing benefit obtained with Vibrant Soundbridge is significant.

P1-5) Functional results after Vibrant Soundbridge® implantation comparing different coupling techniques

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Background: The Vibrant Soundbridge (Vibrant Med El, Austria) has been established in the treatment of sensorineural and conductive and mixed hearing loss. An effective and reliable coupling of the active middle ear implant's (aMEI) Floating Mass Transducer (FMT) is necessary for optimal energy transfer from the FMT to the inner ear via the oval or round window. Therefore, different techniques including a variety of titanium and silicon coupling elements have been developed. We here compare the audiological outcome for the different coupling techniques.
Method: A total of 39 Vibrant Soundbridge aMEIs have been implanted between July 2011 and March 2015 in our department. The FMT was coupled to the incus ("Incus-Vibroplasty") for sensorineural hearing loss in 7 cases (5x SoftCliP; 1x Long process Incus coupler, 1x short process incus coupler). It was coupled to the round window ("RW-Vibroplasty") in 12

cases (9x titanium coupler, 3x silicon coupler), to the stapes via a PORP-coupler ("PORP-Vibroplasty") in 9 cases, directly to the stapes suprastructure ("Stapes-vibroplasty") in 7 cases, and to the stapes footplate using a TORP coupler ("TORP-Vibroplasty") in 4 cases.
Results: One patient with RW-Vibroplasty with profound mixed hearing loss and diabetes mellitus progressively lost hearing due to an infection with complicated wound healing after open mastoid cavity revision and obliteration after multiple previous surgeries. All other patients significantly improved after Vibroplasty with respect to speech discrimination in quiet (monosyllables), hearing in noise (condition: S90, N-90), and in sound localization. We did not see any significant differences between the different coupling techniques.
Conclusions: With the available coupling techniques a reliable energy transfer from the FMT to inner ear can be realized in nearly any middle ear pathology.

P1-6) Is the output of electro-mechanical transducers affected by mastoid cavity obliteration?

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Background: The intended ambient medium of implanted electro-mechanical transducers of Active Middle Ear Implants or Direct Acoustic Implants is the air-filled middle ear cavity. However, when implanted in an obliterated radical mastoid cavity, they may be surrounded by fatty tissue of unknown elastic properties. Here the Young's modulus of this tissue was determined experimentally and the effect of obliteration on transducer output was investigated in vitro.
Methods: Indentation tests of human fatty tissue samples (diameter 3mm) taken fresh from the abdomen or from the radical mastoid cavity during revision surgeries were performed. From these test results the Young's moduli of the samples were determined. Two phantom materials were identified having Young's moduli similar and higher (worst case scenario) compared to the tissue. The displacement output of three commonly used transducers (Codacs™, MET® (Cochlear Ltd); FMT (Med-EL)) embedded in the phantom materials in a model radical cavity was measured with Laser Doppler Velocimetry and compared to the unloaded output.
Results: The Young's moduli determined here for fresh human abdominal fatty tissue were comparable to published values for human breast fat. Embedding the transducers in the phantom material decreased the displacement output amplitude in the frequency range 0.5 – 10 kHz maximally 5.5 dB (Codacs™), 5.1 dB (MET®) and 4.1 dB (FMT). The resonance frequencies were shifted less than 50 Hz.
Conclusion: Using the here developed method, the effect of obliteration on the mechanical output of electromechanical transducers can be estimated in vitro. Our results demonstrate that the expected decrease in vibrational output of the electromechanical transducers investigated here in obliterated mastoid cavities is minor and has no major impact on clinical indication.

P1-7) Long-term results of incus vibroplasty in patients with moderate to severe SNHL

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Objective: For more than one decade the Vibrant Soundbridge (VSB, Med-El) is successfully used to treat sensorineural hearing loss (SNHL). The aim of the study was to assess the safety and effectiveness of the VSB in moderate-to-severe SNHL up to a mean duration of 11.1 ± 2.1 years after the intervention.
Subjects and Methods: 104 German speaking adults (for 122 implants, 50 women, 54 men) with pure SNHL and the VSB coupled to the incus were included in a retrospective, monocentric study. In this group children and mixed hearing loss cases (ABG > 20 dB) were already excluded. Audiological outcome and speech intelligibility was assessed in patients at different time points in non-overlapping groups.
Results: Pre- and post-operative thresholds shortly after surgery (group 1: < 1 year; avg. 0.5 yr (0.1 - 0.8 years; N = 34) revealed a small (< 3.2 dB), but significant drop in bone conductions (BC) thresholds at high frequencies (> 3 kHz) that disappeared in group 2 (1 < 4 years; avg. 2.4 years; N = 51). A decrease in BC thresholds at longer periods after implantation (group 3: 4 years < group 3 < 8 years and group 4: > 8 years) was found comparable in size to the natural hearing loss. Statistical analysis indicated no accelerated progression compared to the contralateral, non-implanted side in monaurally implanted subjects. Also the functional gain and monosyllable intelligibility was still satisfactory in the long-term group (group 4 > 8 years; avg. 11.1 years; min: 8.2 – max: 13.9 years; N = 16).
Conclusion: Comparison of pre- and post-operative BC thresholds detected neither impact on inner ear integrity nor SNHL acceleration by the implantation. Functional gain and monosyllable intelligibility was still satisfactory in long-term (> 10 years) follow-up.

P1-8) Mechanical stabilization of a free-floating fully implantable hearing aid

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Background: We examine a mechano-acoustic transducer inserted into the incudostapedial joint gap. The transducer comprises one piezoelectric sensor and two independent piezoelectric actuators. Maximum gain of the device is limited by feedback between sensor input and the output of the primary actuator. The secondary actuator is used as a compensation unit (CU) to stabilize the system so as to increase maximum gain.
Methods: We examine a 10:1 scale model of the proposed transducer and compare the results with FEM-simulations and with results from temporal bone studies with a similar two-piezo device. An LMS-based control algorithm is used to drive the secondary actuator. It is implemented on a field programmable gate array (FPGA, NI PXI-7842, National Instruments). Dynamic range, functional gain, and added stable gain are determined.
Results: Through use of the CU as a feedback compensator, an added stable gain of up to 46 dB is achieved, leading to a functional gain of more than 35 dB at frequencies above 1000 Hz. These results are similar to those of purely computational feedback control and in accordance with simulation. In the high frequency end of the spectrum, the output increases slighty (<5 dB) due to added virtual mass.
Conclusion: The complex three-piezo system is stabilized very well with the aid of the mechanical compensation unit and performs slightly better at high frequencies than a two-piezo system. However, the improvement is small compared to the intricacy of miniaturized assembly of a three-piezo system.

P1-9) Signal Modulation for optical induced tympanic membrane vibrations

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Background: Pulsed laser light applied at the tympanic membrane (TM) induces vibrations that activate the hearing system. However, controlled activation of defined frequencies of the auditory system is necessary to code complex signals, like speech. Hence, the objective of our project is to develop methods that would enable the activation of the complete audible frequency-spectrum using monochrome laser pulses. We herein report our results regarding the vibration spectrum induced through the application of different laser pulse sequences.
Methods: We inserted ex vivo a 105 µm diameter optic fiber into the outer ear canal of guinea pigs, and directed it towards the TM. Using a scanning Laser Doppler Vibrometer (LDV, Polytec GmbH, Waldbronn) we analyzed the velocity of the vibrations after application of 10 ns laser pulses, pulse energies of 0-16 µJ/pulse, pulse rate of 100-40000 pps and pulse trains of 1-10 pulses (532 nm Q-switched, INCA-laser system, Xiton Photonics, Kaiserslautern). We calculated the displacement from the recorded velocity data and analyzed the results in the time and in the frequency domain.
Results: Increasing the number of laser pulses per stimulation unit led to a definite peak of the spectrum corresponding to the laser pulse rate. With more complex laser pulse patterns, it was possible to induce TM vibrations with a stronger and more precise main peak. By changing the temporal parameters of the laser pulse patterns, this peak could be shifted in a controlled manner.
Conclusion: The results demonstrate that TM vibrations with various frequencies can be induced using a monochrome laser system. Further studies regarding the effect of the application of more complex laser pulse patterns at TM level in vivo are on the way.

P1-10) The Hannover coupler: stimulation of the round window by the floating mass transducer at static contact forces

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Background: Placement of the MED-EL Vibrant Soundbridge Floating Mass Transducer (VSB-FMT) at the round window (RW) has become a clinically well-established method of cochlear stimulation. However, this approach still suffers from large variability in coupling efficiency between RW and FMT. The goal of this study was to decrease variability and to increase the coupling efficiency by a specially designed coupler that allows vibration of the FMT in combination with a static

force preload to the RW.
Methods: Fresh human temporal bones compliant to the ASTM standard (F2504-05) were used in experiments. The Hannover coupler prototype consisted of a prosthesis with a spherical tip (d=0.5 mm) and a hook shaped spring attached to the FMT that allows mobility in combination with the application of static preload. Under stepwise displacement into the RW resulting in forces between 0 - 100 mN, the stapes footplate (SFP) displacements to RW and sound stimulation of the tympanic membrane were measured by a Laser Doppler Vibrometer. From SFP displacements to FMT and sound stimulation the transfer function and equivalent sound pressure levels (SPL) were calculated at different forces.
Results: Six temporal bones compliant to the ASTM standard were included in the analysis. SFP displacements to FMT stimulation were found to be highly dependent on the applied RW-force increasing by 10-27 dB at frequencies ≥ 1 kHz while decreasing by 19 dB at 500 Hz at 100mN. Also increasing force lead to an increase in eq. SPLs of 14-37 dB at frequencies ≥ 1 kHz.
Conclusion: Static force preload applied to the RW is an important factor for transmission efficiency. At a static preload of 100 mN, SFP displacement amplitudes and eq. SPLs showed an increase of > 20 dB at frequencies ≥ 1 kHz.

P1-11) Vibro-EAS: a proposal for electroacoustic stimulation

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Introduction: Electric acoustic stimulation (EAS) uses both cochlea implant (CI) technology to restore severe-to-profound hearing loss at high frequencies and acoustic amplification for mild-to-moderate hearing loss in the low-to-mid frequency range. More patients with residual hearing are becoming candidates for EAS surgery due to the improved techniques for hearing preservation. Most patients with partial deafness fulfill the audiological criteria at low and mid frequencies for the active middle-ear implant Vibrant Soundbridge® (VSB). The floating mass transducer (FMT) of the VSB is a potential device for acoustical stimulation in EAS.
Hypothesis: In-situ evaluation of the vibration performance of a hybrid system for intracochlear fluid stimulation, constructed from a FMT coupled to an EAS CI electrode.
Methods: In seven fresh human temporal bones, stapes amplitude responses for fixation of a FMT to the long incus process (standard coupling) was compared with those for FMT fixation to a 20-mm inserted standard cochlea electrode array (31.5 mm) via the round window (Vibro-EAS). Vibration of the stapes footplate was measured by laser Doppler vibrometry (LDV).
Results: For 0.316 Vrms drive voltage, stimulation of the intracochlear fluid using a FMT-driven CI electrode (Vibro-EAS) yielded stapes amplitude responses comparable to those for acoustic stimulation with 84 dB SPL. These amplitude responses are 30 to 42 dB lower at frequencies up to 4 kHz than those for VSB standard coupling.
Conclusion: Intracochlear combined electrical and mechanical stimulation may be a viable technique for electroacoustic stimulation. A reliable technique for attachment or integration of the FMT to the cochlea electrode array has yet to be developed.

Session P2

Topic: ME Biomechanics

P2-1) 3D displacement measurements of the middle ear ossicles in the quasi-static pressure regime using new x-ray stereoscopy technique

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Background: 3D motion of the middle ear (ME) ossicles is of great importance to understand the role of middle ear in hearing sense. Nevertheless the ME behavior at quasi-static pressure regime attracted more attention since it occurs on daily basis and reported to have an influence on the hearing. However, the behavior under such circumstances is not fully understood yet.

Method: An approach was developed to study the 3D motion of both gerbil and rabbit ME ossicles in the quasi-static pressure regime. The method makes use of the x-ray stereoscopy technique, which provides the 3D amplitude of the motion event, combined with the greyscale information obtained from the x-ray shadow images. This way, the full observations of the 3D ossicles motion as a function of peak-to-peak pressure amplitudes from 0.5 kPa to 2 kPa with frequencies ranging from 0.5 Hz to 50 Hz was achievable. In addition, the ossicular chain motion is demonstrated on high-resolution computer models in order to better visualize the ossicles behavior.
Results: The ossicles showed non-linear behavior as a function of both pressure and frequency. For instance, about 80% of the umbo displacements occur at a 1 kPa (peak-to-peak) pressure load, while a limited increase of the amplitude is noticed when the pressure goes to 2 kPa. The transferred displacement from the umbo toward the cochlea in a rabbit showed ratios of 0.35 for a pressure of 2 kPa (peak-to-peak) at 0.5 Hz and 0.36 when the frequency increases to 50 Hz.
Conclusion: The results showed that the new approach of x-ray stereoscopy combined with greyscale analysis along the path of moving ossicles opens up new possibilities to measure the ossicles motion in 3D. Moreover, the nonlinearity of the ME ossicles motion appears to be more at the very low frequencies than at high frequencies.

P2-2) A novel implantable intracochlear acoustic receiver to quantify airborne sound transformation and transmission through the middle ear

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Background & aims: Transformation and transmission of airborne sound through the middle ear to the cochlea are key biomechanical processes for hearing that can be measured with different techniques. However, in-vivo evaluation methods of the pressure change in the cochlea are limited by the portability of existing devices. This project aims to develop an intracochlear acoustic receiver (ICAR) that measures the inner ear pressure and in addition it is designed to replace external microphones of existing cochlear implant (CI) systems. This concept will be an important step towards a totally implantable CI system.
Methods: Prototype ICAR, based on commercially available MEMS condenser microphones, have been customized for sound measurement in a fluid environment and applied in cochlea pressure measurements. Prototype sensors have been inserted at different locations in the inner ear of fresh temporal bones. The sensor's position was controlled by a custom micromanipulator system and verified with a subsequent CT-scan and 3D reconstruction of the temporal bone. Acoustic stimulation in the range of 200 Hz to 10 kHz was applied in the ear canal and recorded as a reference signal near the tympanic membrane.
Results: Preliminary results confirm that the ICAR prototype is capable of measuring the inner ear pressure, and show dependence on stimulation level, sensor insertion depth and access location. Measurement repeatability has been confirmed and preliminary pressure results are comparable to published data.
Conclusions: Preliminary results confirm that a MEMS condenser microphone is a promising technology for measurement of intracochlear fluid pressure. Future work will include mapping of inner ear pressure at different access positions and insertion depths in human and sheep inner ears.

P2-3) Contribution of the incudo-malleolar joint to middle-ear sound transmission

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Background: The incudo-malleolar joint (IMJ) interconnects the malleus and incus in the human middle ear. Mobility of the human IMJ under large pressure changes is generally accepted, whereas, the mobility under physiologically-relevant acoustic stimulation and its functional role in middle-ear sound transmission are still under debate.
Methods: In this study, the spatial stapes motion in six fresh human temporal bones was measured under acoustic stimulation (0.25-8 kHz) for two conditions; mobile IMJ and experimentally-immobilized IMJ. The velocity was measured at multiple points on the stapes footplate using a scanning

laser Doppler vibrometry (LDV) system, and 3D motion components of the stapes were calculated with mobile and artificially-immobilized IMJ. The IMJ was immobilized by gluing the intra-articular space together under the microscope, and the immobilization was confirmed by measuring relative motion between the malleus and the incus.
Results: A significant (p = 0.007) frequency-dependent difference of the piston-like motion between the mobile and immobilized IMJ was observed. The IMJ was shown to be mobile at higher frequencies above 2 kHz under physiologically relevant acoustic stimulation of 90-110 dB SPL. The difference was prominent from 2-4 kHz and 5.5 kHz. Difference in the pattern of the stapes motion was not observed.
Conclusion: Mobility of the human IMJ was observed, especially at higher frequencies. It is still being debated whether the mobility of the IMJ in temporal bone measurements is caused by the age of the donors or a protection mechanism.

P2-4) Estimation of the young's modulus of the human pars tensa from in situ pressurization measurements

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Background: Accurate estimates of the Young's modulus of the pars tensa are required in finite-element (FE) modeling studies. Previously, we introduced an in situ estimation technique in which an FE model was optimized to match experimental data acquired during tympanic membrane pressurization in a rat. Unlike previously reported indentation techniques, this pressurization approach could be performed with the tympanic membrane in situ and it did not require cutting strips from the pars tensa, which could potentially affect its mechanical response. To the best of our knowledge, this technique has never been applied to a human eardrum.
Objectives: To apply our pressurization-based approach on human eardrums to estimate the Young's modulus of the pars tensa.
Method: A freshly frozen cadaveric temporal bone was used in this study. The malleus head was immobilized to isolate the eardrum movement and allow for accurate modeling. The middle-ear cavity was pressurized to 500 Pa and the deformed shape of the eardrum after pressurization was measured using a Fourier transform profilometer (FTP). To simulate the pressurization experiment, a specimen-specific FE model of the eardrum at rest was defined from a 3D micro-computed tomography (micro-CT) image. Micro-CT was used instead of FTP since the latter did not allow visualization of the entire eardrum, especially near the tympanic ring. The Young's modulus was estimated using Nelder-Mead optimization, which compared the deformed FE model shape to the measured shape after pressurization.
Results: The estimated Young's modulus was 1.4 MPa. Changing the initial parameters used by the optimization algorithm by two orders of magnitude only caused a 1% variation in the results.
Conclusion: The Young's modulus estimated using the pressurization approach is comparable to reported values using an in situ indentation technique, but it is smaller than values reported on tissue strips. The optimization approach is robust to initialization.

P2-5) Finite-element modelling of the synovial fluid and contact in the incudostapedial joint

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Introduction: Previously we analyzed the small-amplitude low-frequency coupling between the incus and stapes in a finite-element (FE) model by introducing a refined geometrical description of the pedicle of the lenticular process, based on histological serial sections and X-ray micro-CT, and using a-priori estimates for material-property parameters (Funnell et al., JARO 2005). However, for that model the presence of synovial fluid was neglected. More recently we measured the response of the middle ear to large static pressure loads. From the sliding and relative rotations observed in the ossicular joints it became clear that a better representation of the joints is required.
Materials and Methods: The present contribution focuses on the modelling of the incudo-stapedial joint (ISJ) for static pressure loads in the ear of the gerbil, and in particular on explicitly including the effects of the interstitial synovial fluid. The overall model geometry is a 3-D reconstruction based on micro-CT. The anatomical details of the ISJ were derived from histological serial sections. A finite element model using linear tetrahedral elements was created of the geometry, including the lenticular process as well as the joint capsule and the synovial fluid. The simulations were done using FEBio, a freely distributed FE package especially developed for bio-engineering purposes at the University of Utah (Maas et al. , JBME 2012).
Results: The effect of the synovial fluid between the lenticular plate of the incus and the upper surface of the stapes head was modelled using different approaches and will be discussed.
Conclusions: The presence of synovial fluid in the joint between the incus and the stapes, which allows for sliding between the contacting surfaces and for opening of the gap between them, appears to have a substantial effect on the behaviour of the joint under static pressure loads applied to the ear canal.

P2-6) Impedances of the human ear

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Introduction: Different forms of sound conduction to the cochlea can have different volume velocity pathways, depending on the impedances that these pathways face. For air conduction (AC) stimulation of the ear, the volume velocity of the stapes nearly equals the volume velocity at the round window (RW). In RW stimulation, however, there is evidence that significant volume velocity 'leaks' through other pathways. Here we analyze the different volume velocity pathways and cochlear impedances using intracochlear pressure and extracochlear volume velocity measurements in terms of lumped model representations of the cochlear impedances.
Methods: In fresh human temporal bones, we measured stapes and RW velocities, scala vestibuli and tympani pressures and ear-canal pressure during AC and RW stimulation. From the AC stimulation experiments we determined the impedances of the cochlear partition (basilar membrane), ZBM, and round window, ZRW. Assuming that ZBM remains constant between AC and RW stimulation, we calculated the reverse middle-ear impedance ZME and the leak in scala vestibuli ZlkSV, from RW stimulation results.
Results: ZBM was modeled as a pure resistance. ZRW was modeled as compliance in series with a Foster-form iterated network of 6 parallel branches made up of inductances and resistors in series. The resulting ZRW was dominated by compliance below 500 Hz, and mixed inductance-resistance that varied with frequency above 500 Hz. The leak in the scala vestibuli ZlkSV is modeled as a compliance and resistor in series.
Conclusion: Various impedances in the cochlea and their relationship across frequency were obtained by our experimental measurements of intracochlear pressures and velocities. Simple lumped element models of the impedances simulated well the measurements in both magnitude and phase. Future experiments and modeling will determine other cochlear impedances.
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P2-7) Sound pressure distribution in natural or artificial human ear canals in response to reverse mechanical stimulation

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Introduction: Though the distribution of sound pressure in the human ear canal (EC) has been characterized for sound stimuli presented to the EC entrance (forward stimulation), not much is known of the EC sound pressure distribution when the sound is generated by tympanic membrane (TM) motion (reverse stimulation), as with otoacoustic emissions (OAEs). Misestimation of OAEs due to sound pressure variations may complicate their interpretation.
Methods: Human temporal bones were prepared by removing the cartilaginous ear canal and opening the facial recess of the middle ear, leaving the bony EC mostly intact or replaced by an artificial EC. The incus was stimulated mechanically by a small piezoelectric actuator to produce TM motion. Sound pressure responses to broadband stimuli were measured at ~70 locations across the TM surface (Ptm), in a plane transverse to the EC axis 4-6 mm distal to the umbo (Pec), and along the EC axis with a small microphone and calibrated probe tube.
Results: In contrast to the normal forward acoustic stimulation case, in which sound pressure was nearly uniform across the TM surface below about 10 kHz and varied slowly and regularly with distance from the EC entrance at higher frequencies, Ptm with reverse mechanical stimulation showed considerable irregular spatial variation across the TM surface in narrow frequency bands at frequencies as low as 5 kHz. Pec distribution in a transverse plane was nearly uniform except at isolated frequencies. Longitudinal sound pressure variations along the EC axis were consistent with a simple uniform tube model.
Conclusions: Significant local transverse sound pressure variations are produced by TM motion but dissipate within 4-6 mm of the TM. The choice of the best location to measure OAEs above a few kHz involves a tradeoff between longitudinal and transverse Pec variations.
Funding: NIDCD, MEEI, and the Mittal Fund.

P2-8) Time variances of vibration transmission properties of human temporal bones

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Background: The human temporal bone is a standard model in experimental hearing research. Over short periods of time and moderate excitation levels it can be regarded as linear and time invariant. In practice, extensive measurements sometimes must be conducted using the same specimen for several hours. Then the vibration transmission properties cannot be presupposed to be constant.
Methods: To determine the influence of time variances, we performed repeated measurements without any manipulation on 10 temporal bones (fresh or frozen and then thawed) over five hours in 10 minutes intervals. We simultaneously measured sound pressures in an artificial ear canal, sound-induced stapes velocities and either round window velocities or sound pressures. As parameters for the time invariance we used the difference between the first and last measurement and the standard deviation of the repeated measurements.
Results: Time variances of all measurands showed great interindividual differences. Ear canal sound pressures showed the smallest time variance, whereas stapes velocity changes were about 6 dB higher at most frequencies. The highest deviations were found in round window velocities and round window sound pressures. Their standard deviations exceeded 10 dB in many cases.
Conclusion: Vibration transmission properties of human temporal bones as biological systems can vary over time. These time variances seem to reach magnitudes of practical and clinical relevance. This should be considered when setting up temporal bone studies and discussing their results.

P2-9) Transient measurements of 3D ossicular vibrations due to impulse stimuli

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Background: The presence of three distinct ossicles in the middle ear is a ubiquitous and uniquely mammalian trait, yet the benefits conferred by this complicated anatomy are still debated. We hypothesize that this elaborate three-bone structure introduces sources of flexibility, such as in the ossicular joints, which provide passive protection by dispersing potentially damaging impulsive stimuli beyond the effects provided by an eardrum delay.
Methods: The 3D velocity of 12-15 points along the ossicular chains in unaltered cadaveric human and mouse specimens was measured in the time domain using a Polytec CLV-3D laser Doppler vibrometer. Measurements were repeated after fusing the ossicular joints. SyncAv (ver 0.26) was used to generate impulsive stimuli while pressure near the tympanic membrane was synchronously recorded using an ultrasonic probe tube microphone. Impulse characteristics included peak pressures near 140 dB SPL and impulse widths of less than 100µs. 3D models of the ossicles were reconstructed from µCT scans, and the transient 3D motion of the ossicles was calculated using a least-squares fitting algorithm.
Results: The ossicles demonstrated a ringing response to the impulses, and velocity amplitude generally decreased along the ossicular chain from the umbo to the stapes. A phase delay along the ossicular chain was also noted. Relative motion between the malleus and incus was observed in the normal cases, indicating slippage at the malleus-incus joint. Fusing the joints removed this slippage and changed the vibration pattern of the ossicles.
Conclusion: These measurements represent the first investigation of 3D transient ossicular motion in the time domain. Slippage at the malleus-incus joint and the change in ossicular vibrations after joint fusion suggest that flexibility in the ossicular joints plays a role in determining the transient ossicular response to impulsive input to the middle ear.
Work supported by R01DC05960 and FDC013943A from the NIDCD of NIH.

Session P3

Topic: Bone Conduction

P3-1) Bone conduction response of the round window in Thiel-embalmed cadaver heads with normal middle ear, stapes fixation, fenestration and prostheses.

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Background: Carhart's notch, a bone conduction hearing loss around 2 kHz, characterizes inner ear function in patients with otosclerotic stapes fixation. Bone conduction is frequently improved after stapes surgery and thus the Carhart's notch is assumed to be of micromechanical cause. Using laser Doppler vibrometry (LDV) at the middle ear structures of Thiel-embalmed heads, our study aims to determine if changes of the cochlear micromechanics due to alterations at the ossicle chain can be estimated by LDV measurements at the RW.
Methods: The motion of the retroauricular skull, the promontory, the stapes footplate and the round window (RW) were measured using single point LDV in six ears of four

human whole head specimens embalmed according to Thiel. A bone-anchored hearing aid stimulated the ears with 37 step sinus tones between 0.1 and 10 kHz. The influence of different ossicular chain conditions was assessed with mobile ossicle chain, cement-fixed stapes, stapedotomy, piston-prosthesis, stapedectomy and Schuknecht wire-tissue-prosthesis
Results: The fixation of the stapes induced a lowered mean RW displacement for frequencies below 1 kHz (max. -4dB at 750Hz) and an increased displacement for frequencies above 1kHz (max. +3.7dB at 4 kHz). Stapedotomy resulted in an opposite effect. Stapedectomy led to a lower RW displacement compared to stapedotomy at frequencies between 2.5 and 3 kHz. The Schuknecht prosthesis showed a higher RW velocity at frequencies below 0.4 kHz than the piston prosthesis.
Conclusion: The vibratory response of the round window to bone conduction stimulation is affected by different conditions at the level of the stapes, indicating a measurable effect of changes in ossicle chain inertia or oval window impedance in Thiel embalmed heads. Our results support the assumption that the clinical improvement of the BC threshold after fenestration of a fixed stapes footplate can be at least partially explained mechanically.

P3-2) Enhancement of excitation force of new implantable bone-conduction hearing device in low-frequency range

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In our previous research, a new subcutaneously implantable bone-conduction hearing device consisting of an external unit and an internal unit has been proposed. The external unit picks up sounds and transmits the signal to the internal unit by mutual induction between a transmitting coil in the external unit and a receiving coil in the internal unit. A vibrator made of giant magnetostrictive material (GMM) which deforms its length by changing surrounding magnetic field is installed in the internal unit and generates vibration on the skull. Although several prototype vibrators have been developed, the excitation force of the prototypes was inadequate especially in low frequency range. In this study, the transmission efficiency between the transmitting coil and the receiving coil was improved to overcome the deficiency in the excitation force. The efficiency of the mutual induction between the transmitting coil and the receiving coil depends on time rate of change of the current applied to the transmitting coil. To achieve the high transmission efficiency, therefore, amplitude-modulated (AM) wave with high frequency carrier wave was applied to the transmitting coil. To demodulate original audio signals from the AM wave, three types of circuits, i.e. an envelope detector, a combination of clamp circuit and envelope detector, and a voltage doubler rectifier circuit were tried out and the results were compared. The combination of clamp circuit and envelope detector has high output and energy efficiency at all frequencies compared with other circuits. This result provides a prospect of practical use of the new implantable bone-conduction hearing device.

P3-3) Estimation of transcranial attenuation and time delay of bone-conducted sound by a three-dimensional finite-element model of the human head

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Background: Bone conduction hearing aids (BCHAs) are an effective treatment for people requiring amplification, but are unable to use ordinary hearing aids. One important parameter of bone-conducted (BC) sound is the transcranial attenuation (TA) and transcranial delay (TD) as it influences the isolation of the ears in bilateral applications and the efficiency of the BCHA for cross-hearing applications (single sided deafness). A 3D whole head finite element (FE) model enables the computation of these parameters.
Methods: A 3D FE model of the human head was developed and used to simulate the TA and TD. The mastoid position used for audiometry and the bone conduction hearing aid (BCHA) positions were used for BC stimulation and the vibration response was obtained at the cochlear promontories in all three perpendicular directions.
Results: At low frequencies, the TA is close to 0 dB and above 1 k Hz the attenuation increases with frequency. With stimulation at the mastoid, the TA is about 20 to 25 dB at 5 to 19 kHz. When stimulated at the BCHA position, the TA is almost 10 dB lower than at the mastoid at the same frequency range. For both stimulation positions, the TDs are around 0.5 ms at frequencies 1 to 3kHz and less than 0.3 ms at other frequencies.
Conclusion: The TA depends on the frequency and stimulation position. The higher the frequency and the less distance between the stimulation positions and the ipsilateral cochlea, the greater the TA. The TDs seem to be relatively independent of the two stimulation positions used.

P3-4) Inner-ear sources contribution of bone conduction in chinchillas

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While the cochlea is the site where bone-conduction stimuli are transduced into neural responses [Bekesy 1960, Stenfelt et al. 2003], the contributions of the different bone-conduction pathways remain unclear. There are two distinct major routes in bone conduction: the air conduction route that stimulates the outer ear and the middle ear through ear canal compression and middle ear inertia, and the direct inner ear stimulation route that induces cochlear fluid volume velocity through cochlear fluid inertia, cochlear capsule distortion and third-window pathways. Previous work in our laboratory [Songer et al. Hear Res 269, 2010, Chhan et al. Hear Res 301, 2013] suggested inner ear mechanisms are the dominant sources in bone conduction in chinchillas with cochlear bone compression hypothesized to be the main mechanism. We further investigate and quantify the contribution of the different stimulation pathways by measuring intracochlear sound pressures (sound pressure in scala vestibuli Psv and scala tympani Pst near the cochlear base) produced by bone-conduction stimulation in anesthetized chinchillas while manipulating the outer ear and the middle ear.
Ear canal occlusion produces a 10 dB (on average) increase in the Psv produced by skull vibration at frequencies between 0.5 and 3 kHz. With the ear canal occluded, stapes fixation produces a similar sized decrease in Psv over a similar frequency range suggesting the decrease is associated with uncoupling the ear-canal compression source, not the loss of middle-ear inertia. These two manipulations produce little change in Pst. The unequal change in Psv and Pst suggest the influence of compressible cochlea contents or a third window that lead to unequal fluid flow between the oval and round windows in bone conduction, consistent with Stenfelt's work in fluid volume displacement at the two windows in AC and BC [Stenfelt et al. 2004].

P3-5) Objective measurement in single side deafness and conductive hearing loss patients using the Bonebridge (MED-EL, Austria)

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Introduction: This study focuses on the assessment of the Bone Conduction Implant "Bonebridge" (MED-EL) using Laser-Doppler-Vibrometry (LDV, Polytec Inc.) and Outer Ear Canal Sound Pressure Level (OEC-SPL) measurements.
Method: The study includes seven single side deafness (SSD) patients with contralateral intact ossicular chains and no air-bone gap (ABG) and five conductive hearing loss (CHL) patients. All patients were unilaterally implanted with the Bonebridge on the impaired sides. For LDV and OEC-SPL measurements a multi-sine signal with frequencies from 250 to 8000 Hz was used as the stimulus. The displacement was measured intra-operatively by LDV on the surrounding bone close to the implant, whereas the OEC-SPL was measured contralaterally by a probe microphone (Etymotic Research, Inc.) in the external ear canal. Only data with signal-to-noise-ratio higher than 12 dB was used for later analysis.
Result: OEC-SPL and displacement measurements showed a high variability among individual patients (15 to 30 dB). However, there was a high correlation between the average OEC-SPL and displacement in the frequency range between 500 Hz and 6000 Hz in the SSD group (r^2=0.91), while the correlation in CHL group was lower (r^2=0.79). In addition, comparison between the average OEC-SPL in SSD and CHL group showed no significant differences.
Conclusion: The results suggest the implants' function can be clearly assessed at surgical sites using LDV and OEC-SPL measurements. In addition, the result from comparing the CHL and SSD patients indicated the dominant part of the measured sound is emitted by the external ear-canal walls.

P3-6) Optimal position of bone conduction hearing aids without skin penetration

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Background: Attachment of bone conduction (BC) hearing aids (BCHA) without skin penetration, using a headband, allows preclinical evaluation of devices before implantation, as well as application to young children, whose skull thickness is not sufficient for implantation. However, quantification and comparison of BCHA performance under different attachment conditions require appropriate force calibration. Further, evaluation of BCHA performance at its development stages requires identification of an optimal stimulation site in the temporal region. This study aims to compare the efficiency of different coupling conditions and to find optimal stimulation sites of BCHAs in tests without skin penetration.
Methods: The stimulation was calibrated to provide equal output force for the BCHA attached to a steel headband. The BCHA stimulation in the range of 0.2 to 10 kHz, supported by a steel headband, was applied at 8 positions around the ear in three Thiel-embalmed human cadaveric heads, while promontory motion was measured by a Laser Doppler Vibrometer. Additionally, hearing thresholds were measured in twenty normal hearing subjects for the same positions using a Radioear B71 bone vibrator attached via a 5-Newton steel headband.

Results: Applied forces of the BCHA attached to the head with a 5 Newton headband show lower stimulation magnitudes compared to the BCHA attached to an implanted-screw, especially above 2 kHz. Both promontory motions in cadaveric heads and BC thresholds in normal hearing subjects show similar trends, where the responses depend on stimulation location as well as frequency.
Conclusions: Performance of BCHA coupled with a headband can be predicted if the coupling force is sufficient (5 Newtons). The skin affects the mechanical point impedance but does not affect the transmitted force significantly.
Stimulation on anterior region of the ear generates the highest promontory motion and the lowest hearing thresholds.

P3-7) Quantification of the contribution of fluid inertia and bone compression for the hearing of bone conducted sound

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Background: It is generally known that bone conducted (BC) hearing relies on 1) inertia of cochlear fluid, 2) inertia of middle-ear ossicles, and 3) contraction and expansion of outer bony shell of the cochlea, which is called bone compression. However, the dominant contributor for BC hearing at different frequency regions is still unclear. Here, the amount of inertia and bone compression is quantified to investigate the dominant factor to BC hearing.
Methods: Based on the cryogenic images, we developed a finite element (FE) model of a human whole head consisting of skull, brain, soft tissue, cartilage, cerebrospinal fluid, and eye balls. Specifically, the head model contains the human auditory peripheries consisting of middle ear, cochlea, and semicircular canals. In the simulations, the BC input is implemented by applying sinusoidal force on the skull surface. Using this model, the basilar membrane velocity caused by the BC stimulation was calculated. It is assumed that the basilar membrane velocity is inversely proportional to the hearing threshold.
Results: The displacement and volume displacement of the interface between cochlear fluid and cochlear-outer bony shell showing the same magnitude of the basilar membrane velocity was computed. Subsequently, the component causing the greatest basilar membrane velocity for a specific frequency range can be determined.
Conclusion: Using the FE model of the human head including auditory peripheries, the contribution of the inertia and bone compression to BC hearing is quantified. Furthermore, the relationship between the basilar membrane velocity and BC components are also quantified. This study is helpful to clarify which component dominates BC hearing.

Session P4

Topic: Computational Models

P4-1) A measurement of acoustic gain using an ear made by a 3D printer.

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Evaluating acoustic gain in external auditory canal(EAC) accurately is a very important factor for fitting hearing aids. (HA) The conventional measuring method of the acoustic gain in EAC is by using coupler or temporal bones. However, in many countries, it is difficult to get temporal bones because of religious beliefs or other perceived ethical problems. The use of a coupler is different to a real-ear by means of shape, volume and material. Also, the shape of EAC sometimes changes, due to canal wall down technique by middle ear surgery. It is difficult in advance to predict the degree of hearing loss due to surgery.
In this study, we used a three-dimensional (3D) printing technology to create an ear. We compared the acoustic gain in EAC of the 3D printer ear to a real-ear. The ossicles, the EAC and the auricle could be finely reproduced using only CT scanning data, but tympanic membrane couldn't be reproduced. We got similar sound pressure level of acoustic gain on both the manufactured ear and the real-ear, although the peak shifts to highly frequency. The 3D-printer ear can be a useful device for simulating operation and measurement of acoustic gain.

P4-2) A new 3D printed functional human middle ear model

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Introduction: Human temporal bone preparations are used for the evaluation of middle ear (ME) prostheses and for surgical practice, because the sound transmission characteristics and tissue properties can be conserved after exodus. However, their characteristics change with time and vary between individuals. Therefore, a systematic evaluation of prostheses using such preparations requires much effort and time and only few synthetic models exist to evaluate prostheses under reproducible conditions. Here we describe an artificial middle ear with near natural transmission properties.
Methods: A 3D printed functional ME model with the essential anatomical ME structures was built. Structures were segmented from µCT-data. Bony elements were 3D printed and soft tissue was silicone rubber casted in 3D printed casting forms. The tympanic membrane was reproduced as a soft membrane with its unique form, the ossicular chain consisted of real sized fully articulated ossicles and the inner ear was a tube filled with saline closed with a membrane.
Results: Our model enabled standard audiometric tests, such as tympanometry and had similar sound transmission characteristics to human MEs according to the ASTM standard F2504-05. The displacement response to sound had a plateau region ≤ 1 kHz and a roll off above. However, the roll-off-slope was steeper than desired and amplitudes between 125 - 5 kHz were 2-8dB below the 95 % range of the ASTM standard. At frequencies > 5kHz the stapes footplate response was dominated by vibrations of the casing.
Conclusion: The model enables us to imitate the anatomy and functionality of the human ME, providing a reproducible environment for prosthesis evaluation and practice purposes. Our next step will be to evaluate the model by implantation of different types of prostheses. In the future, the model could reproduce the patients' pathologies and may assist in preoperative surgery planning.

P4-3) Comparison of model predictions and acoustical measurements of adult middle-ear disorders and shifts in acoustical stapedius muscle reflex in normal ears

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Background: An acoustical lumped-element and one-dimensional transmission-line model of sound transmission was recently developed for adult human ears with normal function. This study extended the model to predict acoustic stapedial muscle reflex (ASR) patterns in normal ears, and middle-ear transfer functions in ears with middle-ear disorders. Model predictions were compared to measured transfer functions in normal and impaired ears.
Methods: Measured data in adults (0.25-8 kHz) included impaired ears with confirmed ossicular discontinuity, superior canal dehiscence (SCD), otosclerosis, and malleus fixation with hypermobile tympanic membrane, and normal ears with/without the ASR. The eardrum model included one component bounded along the manubrium, and another component with multiple modes bounded by the tympanic cavity, with both eardrum components coupled via a time-delayed impedance. The middle-ear cleft model included the tympanic cavity, aditus, antrum and mastoid air cell system, which had multiple branching airways. The model included ossicular transmission and an inner-ear fluid motion with cochlear and physiological third-window pathways. Model parameters were adjusted to predict transfer functions for each middle-ear disorder, and the effect of the ASR across frequency.
Results: Predicted and measured ASR shifts in reflectance (absorbance and group delay) and (equivalent) admittance at the plane of the eardrum were similar in normal ears. The substantial shifts in reflectance and admittance in ossicular-discontinuity ears relative to normal ears were similar in predictions and measurements. The model predicted increased admittance magnitude and absorbance in SCD ears near 1 kHz, and greatly reduced pressure in the inner-ear vestibule. The model predicted changes in reflectance and admittance in otosclerotic ears associated with large reductions in cochlear transmission. Predictions were less accurate for the ears with a fixed malleus and hypermobile tympanic membrane.
Conclusion: The predictive model may be helpful in interpreting transfer-function measurements under experimental and clinical conditions. (Research supported by NIH grant DC010202)

P4-4) Maturation of the neonatal ear canal: Sweep Frequency Impedance (SFI) and finite element model approaches

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Background: A Sweep Frequency Impedance (SFI) meter, which measures the dynamic behavior of the middle ear by sweeping frequency tones from 100 to 2000 Hz, was recently developed to screen for neonatal middle-ear diseases (Wada et al., 1998, Murakoshi et al., 2013 and Aithal et al., 2014).

In recent chronological SFI tests in neonates, two resonances at approximately 300 and 1000 Hz were observed. In addition, only the lower resonance frequency moved to higher frequencies with an increase of age and finally faded out by 5 months.
Our working hypothesis is that the lower frequency resonance may be related to the soft wall surrounding the ear canal, the maturation of which causes changes and subsequent fade-out of resonance frequency. We evaluate this hypothesis by comparing SFI results with simulation results using the recently reported Finite Element (FE) modeling approach for neonates (Hamanishi et al., ARO meeting 2015).
Methods: The FE model is firstly validated with measurement data of middle-ear admittance and power reflectance (Keefe et al., 1996). Simulated SPL curves were obtained by applying a constant volume displacement equivalent of 80 dB SPL at the ear canal entrance. Then, SPL curves resulting from changes in the Young's modulus of soft tissue of the ear canal (Eec) were compared.
Results: The lower resonance frequencies at 6 days and 5 months after birth in SFI tests are consistent with those in FE simulations with Eec of 30 kPa and 5 MPa, respectively. Moreover, corresponding Eec values increase rapidly after 2.5 months of age.
Conclusions: The lower frequency resonance in the SPL curve is related to the soft wall surrounding the ear canal. The canal wall of neonates initially consists of a compliant layer of cartilage (Anson and Donaldson, 1981), followed by rapid formation of a bony portion after 2.5 months of age.

P4-5) Motional impedance of anti-reciprocal systems

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Motional impedance (Zmot) was introduced [Kennelly and Pierce, 1912] and highlighted by many other researchers early in the 20th century [Littler, 1934, Fay and Hall, 1933, Hanna, 1925]. It refers sensitivity of input observed by changing output conditions. Using Hunt's two-port system parameters (a simplified version of electro-acoustic system), Zmot is defined as −TemTmeZm, where Tem and Tme are transfer impedances, Zm is mechanical impedance of the system Hunt [1954]. Note that the subscript m, e stand for "mechanic" and "electric", respectively. Our goal of this study is to investigate both theoretical and physical answer for the negative real parts shown in the Zmot which violates Brunes positive real (PR) property as well as the conservation of energy law. Specifically, we specify conditions that cause negative resistance in the Zmot using a simple electro-mechanic network model to demonstrate that Zmot(s) is a minimum-phase function, but does not have to be a PR function. It has been demonstrated that any electro-mechanical network with shunt losses in electrical side such as diffusion represented by a semi-inductor cause the negative real part in Zmot.

P4-6) Nonlinearity in the middle ear: measurements and modelling

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Measurements conducted in recent years have detected small nonlinear distortions in the vibration response of the middle ear. A sensitive measurement and analysis method based on the use of multisine excitation signals was used in combination with laser vibrometer to detect nonlinearities at sound pressure levels of 93 dB and above in Gerbils, Rabbits and Humans.
However the source of these nonlinear distortions is not understood. Possible sources are the elastic and damping properties of the tympanic membrane and the ligaments, as well as the membrane's asymmetrical shape. Quasi-static studies of umbo displacement as a function of pressure has shown hysteresis and asymmetry, which obviously causes a nonlinear response. It has been suggested that the tent-like shape of the tympanic membrane may play an important role in this observation.
In order to more closely study the nonlinear behaviour of the middle ear we constructed a finite element model of the tympanic membrane. With this model we were able to examine the effects of the membrane shape and material properties on its nonlinear behaviour.
We will present the results of these simulations, and discuss the likely sources of the middle ear's nonlinear behaviour.

P4-7) Sensitivity analyses of finite-element models of newborn ear canal and middle ear

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Although many studies have reported material properties for various structures of adult middle ears, these parameters undergo significant changes with ageing, particularly in the first months of life, and no measurements of material properties

have been reported for newborn ears. Justification of the material parameters used, at least within a plausible range, is essential in numerical modelling.
In this study, we modelled a newborn ear canal and middle ear using the finite-element method for frequencies from 50 Hz to 2 kHz. Ranges of plausible material-property values were established based on structural similarities between different tissues, reported values for the adult ear, and observed changes from birth to adulthood. We performed two sets of sensitivity analyses, using (1) the traditional one-variable-at-a-time method, and (2) the Morris method. Two different criteria were used to evaluate the effects of each parameter: (1) the maximum admittance magnitude; and (2) the frequency at which that maximum admittance occurs. These analyses not only identify the most influential parameters but also provide information about whether their effects are linear or nonlinear and whether they are involved in interactions with other parameters.
The most influential parameter of the ear-canal model for both criteria is the stiffness of the canal tissue, which also has the most nonlinear effects. For the middle-ear model, the damping ratio affects the first criterion more than other parameters do and it is involved in interactions with other parameters, while the stiffness of the pars tensa alters the second criterion more than the other parameters do. The parameters of the cochlear load have the least effect on both criteria.
The **results** of this study provide insight into how different parameters affect the function of the newborn ear, and which parameters require further attention in order to reduce their uncertainties.

P4-8) The biomechanics of hair bundles injury in lateral crista ampularis of guinea pigs

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Purpose: To observe the morphological changes of lateral crista ampullaris under scanning electron microscopy (SEM) and analyze the cupular shear strain changes of lateral semicircular canal (LSC) in guinea pigs with Endo- lymphatic hydrops (EH).
Methods: EH were established in 10 guinea pigs by obliterating endolymphatic sac in right ear. The cupula was removed, fixed, coated with gold and examined with SEM. Finite element simulations of lateral semicircular canal were also calculated: The two-dimensional (2D) finite element models of LSC with and without EH in guinea pigs were developed according to the diameters measured based on three- dimensional reconstructions of five guinea pigs in each group and the rotation of LSC were simulated using the numerical models.
Results: 1. Morphological changes under SEM showed that the cuticular plates in some peripheral area of crista were ejected and the basilar papilla epithelium was composed of cells with no hair bundle in some traumatized areas of crista in EH group; 2. The location of maximum cupular shear strain for each time during the rotations was always at the bottom of the cupula, which was near the top of crista. The most absolute values and amplitude of shear strain in EH were greater than that in normal group.
Conclusion: The area of hair bundles loss in crista ampullaris was consistent with the location of maximum cupular shear strain in guinea pig with EH. The shear strain was one of the factors for the hair bundles injury.

Session P5

Topic: Diagnostics

P5-1) Cochlear depression after c-Vemp exposure

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Background: High stimulation levels, tone bursts of 130 dB SPL, are common to evoke cervical vestibular evoked myogenic potentials (c-VEMP test). It is not known if the intense low frequency stimulation required to elicit reliable potentials is hazardous for human hearing.
c-VEMP-testing is used routinely to evaluate if symptoms of altered middle and inner ear mechanics such as conductive hearing loss with supra normal bone conduction, unilateral pulsating tinnitus, sound induced vertigo and/or autophonia is related to the third window effect of a dehiscence in the labyrinth bone. Hearing acuity before and after VEMP-test was assessed to investigate the safety of c-VEM-testing.
Method: Hearing acuity was evaluated in 24 patients before and after c-VEMP-test consisting of 192 tone bursts at 130 dB SPL. The hearing sensitivity was tested by fixed frequency Békésy thresholds at 0.125-8kHz and the I/O functions of distortion product otoacoustic emissions (DPOAEs) with stimulation levels between 50 and 80 dB SPL at 0.750 and 3 kHz.
Results: The c-VEMP-testing induced a statistically significant negative DPOAE shift of 2 dB at 3 kHz. A negative but not significant trend could also be seen in the DPOAE at 0.75 kHz.

No effect was seen in the Békésy thresholds.
Conclusion: In the absence of a negative shift in audiometric threshold we consider c-VEMP testing according to our paradigm to be safe. The negative shift in DPOAE is half of what is seen after exposure at sound levels equivalent of the maximally allowed sound energy level for an 8-hour workday. However the depression in emissions indicates that c-VEMP testing has a slight negative affect on the inner ear and the tone burst stimulation should be kept at the minimum of what is required to obtain reliable testing. c-VEMP-testing should not be repeated on the same day if registration fails.

P5-2) Evaluating a new method for clinical measurement of METF - theoretical and experimental investigations

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Introduction: Defects of middle ear structures are reconstructed with passive and active middle ear implants. At present, the result of the reconstruction can only be evaluated by audiometry after the operation. For reasons of surgical quality control and middle ear reconstruction optimization, a method to measure the middle ear transfer function (METF) during surgery is imperative. Common acoustic stimulation cannot be used in many cases due to the surgical procedure, thus, a different but comparable stimulation method is required.
Methods: In order to accomplish this, an electromagnetic stimulation, with separated coil and magnet, was used. Similar systems have already been used in hearing aids. The magnet is placed at the umbo and the coil around the head (or specimen, respectively). In comparison to the acoustic stimulation, this electromagnetic method applies just a point force with varying contact point and direction of action. The aim of this study was to evaluate the reliability, reproducibility and comparability of the electromagnetic stimulation method. We used temporal bone specimen for experimental investigations and an FE middle ear model for theoretical investigations.
Results: The METF (with electromagnetic stimulation) is not sensitive to the relative coil-magnet position, however, a slightly different positioning of the magnet can cause variations of the METF and different vibration modes at higher frequencies. Although these are poor results for reproducibility, the optimization of middle ear reconstructions do not seem to be affected. First measurements and simulations with ossicular chain reconstructions show comparable results for electromagnetic and acoustic stimulation. For certain points of excitation and at lower frequencies, the electromagnetic stimulation leads to the same results as the acoustic stimulation.
Conclusion: The electromagnetic stimulation seems to be an appropriate and easy to handle method for clinical measurements of METF. While it is a promising solution to optimize middle ear reconstructions, it's reliability must be further evaluated.

P5-3) High frequency bone conduction auditory evoked potentials in guinea pigs: investigating cochlear injury after ossicular manipulation

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Introduction: Surgical manipulation of the middle ear is associated with postoperative permanent high frequency sensorineural hearing loss in up to 25% of patients by mechanisms which are poorly understood. Prominent hypotheses include supraphysiological ossicles movement and drill noise or contact injury. Animal models are needed to explore this phenomenon and evaluate interventions. Because middle ear manipulation may cause both conductive and sensorineural hearing losses, air conduction (AC) evoked auditory potentials are a poor indicator of cochlear function after manipulation. Bone conduction (BC) with clinical vibrators is limited in small mammals by poor transducer output at high frequencies sensitive to injury. We present a model of high frequency BC in both acute and recovery experiments and evaluate the impact of interventions designed to minimise trauma.
Methods: A modified giant magnetostrictive transducer was used to evoke BC auditory brainstem responses, compound action potentials and summating potentials in guinea pigs. The BC responses were compared with a calibrated AC transducer and BC responses normalised to the AC intensity producing equivalent amplitude. Acute and recovery experiments correlated temporary and permanent threshold shifts. The effect of a middle ear traumatising stimulus, actuation of the incudomalleal complex with high frequency oscillation, on evoked potentials was investigated. The influence of endocochlear potential uncoupling was assessed.
Results: BC potentials were reliably evoked up to 32 kHz. There was no significant difference between BC and AC input-output functions. Middle ear actuation caused an acute threshold shift of >15 dB in 90% of animals at 32 kHz, whereas only 50% had threshold shifts at lower frequencies. Preliminary results with Furosemide endocochlear potential

uncoupling indicate some hearing preservation.
Conclusions: Middle ear manipulation induces a high frequency hearing loss in guinea pigs, which may be mitigated, and which can be assessed using BC evoked auditory potentials.

P5-4) Measurement of extended high frequency bone conduction after middle ear surgery

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Introduction: Middle-ear surgeries are typically associated with a high rate of hearing improvement and a low rate of sensorineural hearing loss in the conventional 250 Hz – 8 kHz range. Permanent hearing loss in the extended high-frequency range (8 – 16 kHz), however, occurs in up to 50% of patients, depending on the surgery performed. The mechanisms of this high-frequency loss are poorly understood, but prominent hypotheses include supraphysiological ossicular movement and noise exposure from drilling and suctioning. High-frequency hearing loss could also be conductive in nature and result from changes to the physical characteristics of the conductive mechanism. Previous research has been limited by difficulties in reliably measuring high-frequency bone-conduction thresholds, and thus distinguishing between conductive and sensorineural loss. We present a small pilot study demonstrating that high-frequency hearing loss can be composed of both conductive and sensorineural components.
Methods and materials: A giant magnetostrictive transducer was modified for audiometric use and testing was conducted to establish the reliability and validity of thresholds measured using the device. Air- and bone-conduction audiometric thresholds at 0.5 – 16 kHz were then measured preoperatively and at 1 week, 1 month, and 3 months postoperatively in four patients; three undergoing stapedectomy and one ossiculoplasty.
Results and conclusions: Testing in normal hearing listeners showed that the modified transducer could be used to measure high-frequency bone-conduction thresholds with a level of reliability comparable to standard bone-conduction testing. The pilot study identified two clear cases in which an initial transient conductive high-frequency loss was documented concurrently with a persistent high-frequency sensorineural loss. These results suggest that extended high-frequency hearing thresholds as measured using the modified bone-conduction transducer are a more sensitive measure of operative trauma to the cochlea that may be used to determine the efficacy of interventions to protect the ear from surgical trauma.

P5-5) Modeling the tympanic membrane

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The tympanic membrane (TM) is the most difficult part of the middle ear (ME) to model. It is much like a loudspeaker, running in reverse, converting air born sound into mechanical energy, in a passively and nonlinear manner. Since the ME is ``reciprocal,'' below the quasi-static (QS) limit, its forward transmission is tied to its reverse transmission. When one records OAEs from the ear canal, this reverse transmission is critical. In this presentation we shall explore the relationship between i) TM QSs and higher order TM modes (i.e., TM traveling waves), ii) wide-band acoustic reflectance, and iii) wideband TM impedance/reflectance (WAI). Teasing apart these relationships is critical to understand the physics of the middle ear. As proposed by Zwislocki in 1947, the middle ear and cochlea are a cascade of transmission lines: consisting of the canal, TM, ossicles, cochlea, and tectorial membrane. The ME a beautifully designed instrument for highly efficient (almost lossless), on-linear energy transfer.

Session P6

Topic: Evolution & Development

P6-1) Consanguineous marriages as a factor of the hereditary form of deafness

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Background: Among problems of hereditary pathologies, the most difficult and obscure remains family form of hearing loss. It was observed that children of the spouses - relatives suffer from hereditary diseases more often than children from - unrelated couples.
Customs and laws of many countries prevent the marriage between relatives, and are prohibited by law in most countries. Peculiar insular communities for a long time have been evolved in mountainous remote places in the outer islands. Long-term stability of population, its low migration brought to almost inevitable consanguineous marriages. In the Republic of Tajikistan, there are a lot of remote mountain villages where consanguineous marriages are very common.
Methods: We have studied the material of retrospective research conducted in ethnically not closed village "Marzich" and ethnically not closed village "Ziddi". I.B. Kholmatov and others (1972) examined a group of patients with familial hearing loss, who had close relationship of parents. Usually hearing loss based on consanguineous marriages found in children of healthy parents. In these patients the author

studied the kariotype both in patients with hearing loss, and healthy relatives. In addition, karyological and audiological studies have been conducted in a group of patients with cochlear neuritis.
Results: The researchers noted there more higher level of hearing organ disease than in other regions. Mental retardation, speech defect, hereditary - familial forms of deafness and metabolic diseases more often were registered at local child population.
More than 50% cases of congenital sensorineural hearing loss and deafness have genetic cause.
Conclusion: Special genetic and audiological research conducted by the authors showed that familial form really exist hearing loss among local residents of Tajikistan, which is audiologically characterized by deep cochlear lesions and clearly supports the role of consanguineous
marriages - the factors that contributes to the manifestation of recessive inheritance.

Session P7

Topic: Imaging Technologies

P7-1) Analysis of micro-channel in human mastoid bone using micro-CT scanning

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Background: A previous qualitative analysis has demonstrated the presence of micro-channels in human temporal bone connecting the surface of the compact bone directly to the mastoid air cells (MACS) as well as forming a network of connections between the air cells. These channels are hypothesized to contain a separate vascular supply for the mastoid mucosa. Despite the need to confirm the hypothesis through a histological study, a structural analysis on the micro-channels may improve our knowledge of its anatomical and physiological properties, which may have important implications for our understanding of the pressure regulation of the middle ear.
Methods: This paper proposes a method to describe these micro-channels using a local structure tensor analysis based on micro-CT scanning of 8 human temporal bone specimens. The eigenvalues extracted from the local structure tensor were computed using a set of quadrature filter responses to build probability maps representing planar, tubular, and isotropic tensor types.
The respective tubular, isotropic, and planar tensor types were each assigned one of the RGB color component so as to represent pure cylinders as red, pure planar structures as blue and pure spherical structures as green. Because real data is composed of these three types of structure plus their mixtures, the full structure tensor was rendered along with the original data.
Results and Discussion: New and relevant information on both the shapes of the micro-channels and their connectivity to neighboring mastoid air cells are provided. Before carrying a quantitative analysis, a more accurate representation of the micro-channels in terms of local structure tensor analysis is necessary using both multiple scales and adaptive filtering.
Conclusion: Presence of previously unreported structures leads to new questions concerning the overall nature and structure formed by these micro-channels which may help understanding the potential role of the MACS in pressure regulation.

Session P8

Topic: ME Physiology

P8-1) Bone drilling debris induces osseointegration of microstructured titanium implants on the stapes footplate

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Background: To achieve best hearing result after total ossicular reconstruction a stable and secure prostheses-footplate con-

tact is crucial. Besides commercially available devices for the prevention of dislocation, the endogenous osseoregenerative potential can be used. The aim of this study was to use autologous bone drilling debris to induce an osseointegration of microstructured titanium implants on the stapes footplate.
Methods: Cell culture: Four different microstructured titanium test samples (diameter of 10mm) were covered 20000 cells of the human osteoblast cell line (PromoCell primary human osteoblast, HOB-c). Specimens were cultivated and cell growth was analyzed weekly for 3 weeks regarding proliferation, mineralization and viability.
Animal study: The two surface modifications that performed best in the cell culture were used in the animal study. The experimental prostheses were randomly implanted into 30 Merino sheep. During surgery the stapes suprastructure was removed by a diode laser, the oval cavity on the footplate filled with autologous drilling debris and finally the microstructured implant placed on the footplate. Five different fluorochromes were used 14, 28, 42, 56 and 77 days after operation to mark the ossification process. On day 84 animals were sacrificed, temporal bones extracted and histologically analyzed.
Results: Cell culture: The highest proliferation rate was observed on columnar microstructures, followed by the undercut microstructured samples.
Animal study: In 43 of 56 implants (77%) bone debris induced an osseointegration between the footplate and the implant was observed. A significant difference between the microstructured surfaces was not observed.
Conclusion: Autologous bone drilling debris is a viable source of vital bone forming cells to induce an osseointegration of middle ear implants on the stapes footplate.

P8-2) Local delivery of bisphosphonate to the mammalian cochlea – a prelude to direct delivery in humans via a drug eluting stapes prosthesis

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Introduction: Otosclerosis is a disease of abnormal bone metabolism that affects the otic capsule, which can result in a fixed stapes footplate and present as a conductive hearing loss. Cochlear otosclerosis describes a typically extensive otosclerotic lesion that involves the cochlear endosteum, resulting in a sensorineural hearing loss. We have recently described positive findings following treatment of cochlear otosclerosis with systemic bisphosphonates. However, a local, non-ototoxic, direct delivery method using a drug eluting stapes prosthesis could avoid the potential toxicities of systemic bisphosphonate therapy and allow for increased drug levels within the cochlea and better targeting of otic capsule bone.
Methods: We used a novel, fluorescently labeled compound of zoledronate (FAMZOL) to visualize patterns of bisphosphonate delivery. Guinea pigs were treated with FAMZOL either systemically or locally, via placement on the round window or by direct intracochlear infusion. Hearing was monitored both before and after FAMZOL treatment. We then embedded the temporal bones within resin, ground them down to a mid-modiolar section, and quantified the fluorescent signal within cochlear bone. We also placed FAMZOL in the vestibule of fresh cadaveric human temporal bones and quantified the signal in a similar manner.
Results: Local administration of FAMZOL increased the amount of drug delivered to the cochlea relative to systemic administration, with direct cochlear infusion resulting in the highest levels. Neither systemic nor local delivery of FAMZOL resulted in ototoxicity at doses similar to those given systemically to humans. We have also modeled delivery to the vestibule in fresh cadaveric human temporal bone preparations and identified a gradient of delivery from the base to the apex of the cochlea.
Conclusions: Local delivery of bisphosphonates can be achieved without incurring ototoxicity. Further work is required to determine the optimal effective dose for local delivery of bisphosphonate in the treatment of otosclerosis.

P8-3) The role of bone cell informatics in otosclerosis

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Introduction. Histomorphometric studies of undecalcified temporal bones labelled with basic fuchsin and fluorescent tissue time markers have revealed the unique spatial and temporal patterns underlying otic capsular bone development and degeneration, and has lead to the identification of inner ear OPG, which blocks perilabyrinthine bone resorption and remodeling.
The resulting accelerated aging and excessive degeneration of the osteocytic network and OPG signalling pathway might gradually increase normal bone remodeling in the otic capsule, but in otosclerosis, the morphology of the remodeling bone is abnormal and the distribution is not entirely smooth and predictable, but rather multifocal and chaotic with a predilection at the window regions.
Irregularities in the spatial distribution of bone degeneration could account for this.
Materials, methods and results. Bulk staining of human materials demonstrates the existence of occasional cellular voids in perilabyrinthine bone. Computer simulations of stochastic bone cell behaviour demonstrate how perilabyrinthine clus-

tering of dead osteocytes may develop simply by chance.
Conclusions. Because the anti-resorptive OPG signal is lost inside such voids but preserved in the surrounding bone, abnormal bone remodelling might develop, and proceed until newly formed bone will eventually re-establish the OPG signal. Most likely, otosclerosis is not simply the result of an increased remodelling rate or a deficiency of OPG. More likely, it requires focal degeneration accumulating over time by the action of OPG on bone remodelling, as well as osteocyte irregularities formed occasionally by stochastic cell dynamics.

1. Excessive inner ear OPG + bone remodeling + time => Progressive centripetal bony degeneration
2. Progressive centripetal bony degeneration + variable osteocyte lifespan => Occasional clustering of dead osteocytes = cellular voids
3. Cellular voids + surrounding anti-resorptive signaling network => Perilabyrinthine focal pathological bone remodeling = otosclerosis

Otosclerosis = OPG + Bone remodeling + Time + Cellular variation

P8-4) Vibratory motion of the stapes tendon during sound stimulation

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Introduction: The stapes tendon (ST) attaches the stapedius muscle to the neck and posterior crus of the stapes, stabilizes the stapes over the oval window, and enables active ossicular motion suppression to loud sounds. While the effect of ST tension on stapes motion has been thoroughly assessed, the motion of ST in response to sound stimuli has not been described.
Methods: ST motion was recorded in two cadaveric, hemi-cephalic, human heads. Specimens were prepared with an extended facial recess, and the pyramidal eminence was thinned to improve stapes visualization. Sounds were presented to the ear canal via a custom closed-field loudspeaker system capable of producing very high intensity sound stimulation. ST motion was monitored with a scanning laser Doppler vibrometer during harmonic (20 to 2.5k Hz tones) and impulsive (simulated blast wave) sound presentation.
Results: Motion of the ST is comparable to motion of a taut string with one fixed end. Low frequency stimulation does not elicit resonance, while standing waves are observed in ST at higher frequencies (with maxima near the stapes attachment). Since ST is fixed at the base and driven at the apex, standing waves are expected at frequencies with wavelengths equal to integer multiples of 4x the length (~4 mm). Resonant motion was observed at 640, but not 320 Hz, thus we predict a transverse wave velocity of < ~10 m/s.
Conclusions: Our results suggest that the motion of ST is consistent with that of a stretched string with one fixed end. Thus the damping effect of the tendon on stapes displacement is minimal when the wavelength is an integer multiple of 4x the length of ST, where the lowest wavelength corresponds to < 640 Hz. The stapedius muscle increases ST tension, thus transverse wave velocity, and correspondingly increases this acceptance frequency.
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Session P9

Topic: Pressure Regulation

P9-1) Characterization of eustachian tube opening functions in a hypobaric/hyperbaric pressure chamber

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Background: At pressure difference between nasopharynx and middle ear pressure equalization can be balanced by passive or active equalization system via Eustachian tube (ET). The aim of this study was to characterize standard values for passive openings for the opening pressure (ETOP), the closing pressure (ETCP), and the opening duration (ETOD) in healthy participants.
Methods: In a hypobaric/hyperbaric pressure chamber profile 39 participants were exposed to phases of pressure rising and decompression. The tympanic impedance of the participants was recorded continuously. Data of the Eustachian Tube opening Pressure (ETOP), Eustachian Tube closing pressure (ETCP) and Eustachian Tube opening duration (ETOD) were estimated. In addition we analyzed the pressure gradient during phases of decompression, while the ET was open.
Results: The mean value for ETOP was 30.2 ± 15.1 mbar, for ETCP was 9.1 ± 7.7 mbar and for ETOD was 0.65 ± 0.38 s. Recurring patterns (complete and incomplete openings) of pressure progression during the decompression phase of tube opening were estimated.
Conclusion: Up until now the physiology and function of the Eustachian tube is still difficult to understand. Eustachian tube function measurement in a pressure chamber enables fundamental characterization of the action of the passive tube opening, including the measurement of the ETOP, ETCP and ETOD.

P9-2) In vivo measurements of the middle ear pressure fluctuations during elevator motion: pressure buffering by tympanic membrane displacement

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Background: The tympanic membrane (TM) fulfils a role of partial pressure buffer in middle ear (ME) physiology. This regulatory capacity based on its viscoelastic properties can turn into susceptibility for formation of retraction pockets in a TM weakened by a long-standing ME underpressure. However, predictions of retraction pockets formation require a better basic knowledge about the buffer functionality of the TM, which so far has been described only in models.
The current work offers a set of in vivo continuous measurements of ME pressure variations compared to the ambient pressure variations normally occurring in one common life circumstance: elevator motion. Based on these recordings at low pressure values and a low rate of pressure changes, the purpose of the study was a quantitative analysis of the relative pressure compensation and compliance of the TM under physiological conditions.
Methods: The pressure fluctuations within 7 healthy adult middle ears were continuously recorded during a number of elevator trips using high precision equipment. The volumes of the participating MEs were estimated by Boyle's gas law using measurements of ME pressure changes subsequent to volume-controlled intratympanic gas additions.
Results: Twenty-one elevator trips could be used for analysis. The overall pressure buffer by TM deformation ranged between 4.8 – 55.5 %, with a mean of (22.3 ± 3.3) %. Averaged by subject, it presented a strong negative linear correlation with the estimated ME volumes ($R2 = 0.95$). The compliance for all upward trips was (33.6 ± 6.8) × 10-3 µL/Pa and for downward trips (24.0 ± 6.5) × 10-3 µL/Pa suggesting an asymmetry yet statistically insignificant.
Conclusions: Results are in fair agreement with previous buffer ratios obtained in ME models. In smaller ME's the pressure buffering by the TM becomes more efficient, and thus, in theory obliteration of the mastoid is a favorable condition.

P9-3) Intracochlear pressure behavior of different cochlear implantat electrode insertion techniques

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Hypothesis: Manually and tool guided insertion techniques have different effects on the intracochlear fluid pressure behavior.
Background: Different factors are assumed to contribute to a functional atraumatic insertion of a cochlear implant electrode. The change of the intracochlear fluid pressure by specific insertion steps is a known effect and is assumed to contribute to the degree of hearing preservation.
Material and Methods: We performed cochlear implant electrode insertions in a cochlea model and monitored the intracochlear pressure changes with micro- pressure sensors positioned in the apical region of the model. Insertions were performed by hand, by a manual insertion tool, by a linear actor attached to the tool and completely automatic. All insertions were performed with the same insertion speed.
Results: Comparing the intracochlear pressure changes of the different insertion techniques, the supported insertion modes showed the lowest variations of the intracochlear fluid pressure values.
Conclusion: Tremor related limited manual ability to stabilize a low speed insertion might be a factor which explains the variations between different insertion techniques. Further pathophysiologic insights are needed to correlate intracochlear fluid pressure changes to a functional intracochlear damage. Fully automated and manually supported techniques showed the lowest variations of intracochlear fluid pressure changes.

P9-4) Influence of intracranial pressure und air conducted sound elicited ocular vestibular evoked myogenic potentials: Inner ear mechanics vs middle ear mechanics

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Ocular vestibular evoked myogenic potentials (oVEMP) represent extraocular muscle activity in response to vestibular stimulation. We sought to investigate whether oVEMP are modulated by increasing intracranial pressure (ICP). ACS oVEMP were elicited in 20 healthy subjects lying supine on a tilt table. OVEMP amplitudes gradually declined from 4.59 µV at 0° to 2.24 µV at 30° head-down position, revealing a highly significant reduction of amplitudes for all tilt angles when compared to the baseline value ($p < 0.001$).

Hence, oVEMP were modulated by increasing ICP, in a linear fashion. This effect is most likely due to the increased intralabyrinthine pressure which in turn alters the sound energy transmission from the ear canal to the vestibular receptors.

In a follow-up experiment, we examined whether this effect was dependent on the stimulus frequency in 10 healthy subjects. The subjects were positioned in the horizontal plane (0°) and in a 30-degree head-downwards position in order to elevate the ICP. In both positions, oVEMPs were recorded using 500 Hz and 1000 Hz air-conducted tone bursts. When tilting the subject from the horizontal plane to the 30° head-down position, oVEMP amplitudes in response to 500 Hz tone bursts distinctly decreased (3.40 µV vs. 2.06 µV; $p < 0.001$), whereas amplitudes to 1000 Hz were only slightly diminished (2.74 µV vs. 2.48 µV; $p = 0.251$). Correspondingly, the 500/1000 Hz amplitude ratio significantly decreased when tilting the subjects from 0° to the 30° inclination (1.59 vs. 1.05; $p = 0.029$).

In conclusion, the modulation of the sound energy transmission from the ear canal to the vestibular receptors by an increased intracranial/intralabyrinthine pressure exhibits a distinct frequency-specificity. These findings reveal similarities with oVEMP frequency tuning in Menière's disease and – together with high-frequency tympanometric data – provide new evidence for an increased intralabyrinthine pressure in Menière's disease.

Session P10

Topic: Surgical Techniques and Reconstruction

P10-1) Acoustic properties of collagenous matrices of xenogenic origin as tympanic membrane reconstruction

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Hypothesis: The acoustic properties of decellularized porcine nasel septum cartilages (DECM) made by tissue engineering are comparable to those of human tympanic membranes.
Background: Currently, the reconstruction of tympanic membrane in the context of chronic tympanic membrane defects is mostly performed using autologous perichondrium or cartilage. Autologous tissue may be associated with lack of graft material in revision cases and requires more invasive and longer operative time. Therefore, other materials are investigated for reconstruction. An increasingly important role will be played by tissue engineering.
Methods: The analyzed collagenous matrices (DECM) used in our study consist of porcine nasal septum cartilage, which were harvested and prepared at the Institute of Bioprocess Engineering in Erlangen. To analyze the acoustic properties, the vibrations of DECM, cartilage, perichondrium and tympanic membrane were measured by a laser scanning doppler vibrometer (LDV) under different pressures.
Results: The results of the average volume velocities at atmospheric pressure show a similar curve progression of the tympanic membrane and the DECM with a peak at about 800 Hz. After changing the atmospheric pressure into the negative pressure range (-10,-20 and -30 mbar) the results of DECM, tympanic membrane and cartilage remain fairly constant. However, the volume velocities of the perichondrium drop markedly after changing the pressure into the negative range.
Conclusion: The present study showed that the acoustic properties of the DECM are similar to those of human tympanic membranes. However, in relation to the behavior of the DECM in vivo, further investigations should be carried out.

P10-2) Comparison of manually crimping piston prosthesis and laser-activated nitinol prosthesis in otosclerosis surgery

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Background: Stapedotomy is an established surgical technique for hearing improvement in otosclerosis patients. Manually crimping piston prostheses are widely used, but mechanical crimping around the long process of incus may cause damage. Good hearing results may be declined by too loose or too strong crimping, which may cause incus necrosis. Nitinol, a nickel-titanium shape-memory heat-crimping alloy, prostheses allow heat-activated crimping, which is thought to avoid the problems related to mechanical crimping. The first reports with nitinol prostheses are promising, but information about their efficacy and safety is still scant.
Methods: retrospective charts analysis of 144 consecutive patients who underwent stapedotomy in our department performed by a single experienced otosurgeon (T.P.H.) during 1/2011-9/2014 with either manually crimping prosthesis (K-Piston) or heat-crimping nitinol prosthesis (NiTiBOND). Altogether 105 ears of 100 patients met our inclusion criteria. K-Piston was used in 71 ears and NiTiBOND in 34 ears.

Results: Patient characteristics and preoperative audiologic and surgical details were similar in both groups. Preoperative PTA was 45 ± 1 (mean ± SEM) and 47 ± 2 dB for K-Piston and NiTiBOND groups, respectively. Preoperative ABG was also similar (21 ± 1 vs 22 ± 2 dB). There was no difference in operation time between the groups (41 ± 3 vs 41 ± 3 min). At 3 month's postoperative visit ABG was 5.4 ± 0.9 and 4.8 ± 1.3 dB for K-Piston and NiTiBOND groups, respectively. 97 % of the patients in the both groups had ABG ≤ 20 dB. There was no learning curve effect for using NiTiBOND. The complications were minor in both groups.
Conclusion: NiTiBOND seems equivalent to K-Piston prosthesis in terms of hearing outcome, operation time and postoperative complications in otosclerosis surgery.

P10-3) Design of a new chamber stapes prosthesis

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Background: Piston stapes prostheses are commonly implanted in stapes otosclerosis to stimulate the perilymph and to reduce conductive hearing loss. The postoperative auditory results are considered good but only for low and medium frequencies (0.5–3 kHz). To increase stimulation and improve hydrodynamics of the perilymph, and to reduce the disadvantages of the piston prostheses, we propose a new design of a chamber stapes prosthesis (CHSP).
Our goal was to develop the prosthesis that mimics the natural ear and provides satisfactory hearing results for all frequencies from 0.4 to 10 kHz.
Methods: The CHSP consist of conical chamber (CH), flexible membrane (FM), and rigid plate (RP). The CH ending with a thin tube is designed to be placed into a hole made in the oval window. The CH is filled with fluid and covered with the FM. The RP with an attachment mechanism is fixed to the FM. After attaching this mechanism to the long process of the incus, vibrations are transmitted through the RP to the fluid filled the CH, and then to the perilymph. The CHSP functioning has been numerically simulated. Then, a CHSP prototype was made and experimentally implanted in a human temporal bone.
Results: The simulation results showed that the basilar membrane response with the CHSP is slightly higher (~2–3dB) than for the healthy ear and significantly higher (~10–20dB) than for the 0.4-mm piston prosthesis. Measurements showed that the CH filled fluid merges with perilymph and the vibrations are transmitted to the round window (RW).
Conclusions: The design of the CHSP mimics the natural ear. It may be expected that an appropriate choice of both the geometric parameters and the FM stiffness provide the perilymph stimulation at a physiological level.

P10-4) Face validity of a virtual-reality simulator for training in myringotomy with tube placement

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Background: Myringotomy with tube insertion is challenging for Otolaryngology residents to learn because it is one of the earliest microscopic procedures they encounter.
Objectives: To develop a virtual-reality training simulator and to assess its face validity and training potential.

Methods: An interactive digital model of the ear was created from micro-computed tomographic images and was texture mapped with otoscopic images. Eardrum dynamics were simulated using a mass-spring system that supported cutting with virtual surgical tools. A haptic arm was used to manipulate virtual tools.
To assess face validity and training potential, a questionnaire was developed in consultation with instructing surgeons. Fourteen questions focused on the appearance of the surgical instruments; anatomy of the ear; movement of surgical instruments; deformation and cutting of the eardrum; tube insertion and simulation of a surgical microscope. Six questions focused on training potential on surgical tasks such as speculum placement, microscope positioning, tool naviga-

tion, ear anatomy, myringotomy creation and tube insertion. Survey participants were given a demonstration of the simulator and were allowed to use it until they were familiar with all its aspects and could perform a myringotomy with tube insertion. Participants then answered each question using a 7-point Likert scale.
Results: Responses to 12 of the 14 questions on face validity were predominantly positive. One issue of concern was with contact modeling related to tube insertion into the eardrum, and the second was with the movement of the blade and forceps. The former could be resolved by using a higher resolution digital model for the eardrum to improve contact localization. The latter could be resolved by using a higher fidelity haptic device. With regard to training potential, 64% of the responses were positive, 21% were neutral, and 15% were negative.
Conclusions: The simulator developed in this work appears to be sufficiently realistic for training.

P10-5) Superior tympanoplasty. Denervation of the flaccida region results in impaired pressure regulation.

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Background: Tympanoplasty is a common procedure performed in cases with tympanic membrane (TM) perforations. The majority of these perforations appear in the antero-inferior quadrant resulting from previous repeated treatments with ventilation tubes, and in such cases the tympano-meatal flap is elevated from the floor of the ear canal extending into its anterior wall (traditional tympanoplasty = TT). However, in a smaller number of cases the perforation may appear in the antero-superior quadrant. If the ear canal in such cases has sufficient space, the tympano-meatal may be effectively elevated superiorly from the roof of the ear canal, and the TM mobilized from the manubrium of the malleus to the umbo (superior tympanoplasty = ST). Thus, the complete flaccida region is also elevated.
The flaccida region has been appointed a possible role in middle ear pressure regulation due to its relatively flaccid mechanical properties. Moreover, this region contains many nerve endings though specialized nerve endings have not been demonstrated. Consequently, the ST causing a denervation of the entire flaccida region may result in an impaired pressure regulation reflected by formation of TM retractions in the postoperative course.
Materials and Methods: We identified a test group of 10 cases operated by the ST approach as well as a matched control group of 12 cases operated with the TT approach. The postoperative course included at least a 1-year follow up.
Results: In the test group 5/10 cases developed TM retraction determined by otomicroscopy, whereas in the control group only 1/12 cases were found with TM retraction (Fischer's exact test: p=0.04).
Conclusions: We found significantly more cases of TM retractions in the group of patients with the ST compared to the TT approach. This point to a role of the flaccida region in middle ear pressure regulation, but also additional factors must contribute.

P10-6) Towards direct loading: Results on Ponto, a flexible healing cap and early loading

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Objective: To investigate the use of a newly developed healing cap made of a more flexible and soft material. The healing cap interface allows simultaneous use of the healing cap and the sound processor. The second objective was therefore to investigate implant stability following loading (i.e. use of the sound processors) at the first surgical follow-up visit 7-14 days after surgery.
Methods: Multi-center prospective clinical trial of adult patients eligible for a bone anchored hearing system. The implant stability of the wide Ponto implant was assessed using ISQ measurements. Measurements were done peri-operatively, at the time of loading, as well as postoperatively. After inclusion patients were enrolled in a 12 months follow-up programme with three postoperative visits at 4-8 weeks, 6 months and 12 months postoperatively. Loading of the implant was done 7-14 days postoperatively. Additional parameters included pain, numbness and wound healing, as well as Holger's classification. Per- and postoperative adverse events, if any, were registered.
Results: Currently approximately 20 patients have been enrolled in this study which is ongoing. A single soft healing cap fell off. Early loading was possible for all patients included to this date. No implant loss was encountered and there seems to be no hampering of the development in implant stability after loading.
Discussion: We expect to enroll at least 30 patients. The preliminary results indicate that the flexible healing cap is better than previous designs. Loading as early as seven days post-surgery or possibly even earlier seems feasible using the wide Ponto implant, at least for adult patients with normal bone quality. We will discuss the resulting flexibility in loading time and potential implications for future follow-up schemes after Ponto surgery.

MEMRO 2015 in Hearing Research

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5. **Time line summary:**

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Thank you for your contribution.

John Rosowski
Associate Editor

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